

Intra-sentential code-switching: cognitive and neural approaches

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Bilinguals often produce utterances that switch between languages, such as “I ate *huevos de esta mañana* [eggs this morning]”. The large majority of cognitive and neurocognitive studies examining switching between languages have focused on the processing of a series of single, unrelated items (e.g., unrelated words, numbers, or pictures) rather than switching between languages in a meaningful utterance (e.g., a sentence). However, an emergent body of studies seek to examine the cognitive and neural correlates of language switching in more naturally occurring situations: language switching within meaningful sentences. In this chapter we review recent cognitive and neurocognitive studies on intra-sentential code-switching. We discuss studies that address the question of *why* code-switching occurs and what the mechanisms are that drive bilinguals to switch into the other language. We will also review studies that seek to determine linguistic factors that modulate switching costs in intra-sentential code-switching, in particular the triggering theory. Together these studies attest to the value of integrating linguistic, psycholinguistic and neurocognitive approaches to gain more insight into the neural and cognitive mechanisms of intra-sentential code-switching in comprehension and production.

A unique feature of bilingual speech is that bilinguals often produce utterances that switch between languages, such as “I ate *huevos de esta mañana* [eggs this morning]”. This switching between languages, or code-switching, has been shown to occur in various natural discourse situations. Listeners who overhear bilinguals switching back and forth between languages are often impressed by this seemingly effortless switching between the two languages. Code-switching in a natural discourse situation is one of the few forms of language behavior that overtly reflect that bilinguals have both languages active to some extent, and that they are able to dynamically use one language in some utterances and both languages in others. This merging of two different languages into a coherent utterance not only reveals the flexibility of language processing, but also signifies a highly skilled cognitive control.

The scientific study of code-switching is, therefore, an excellent test bed to examine the cognitive and neural correlates of cross-language interaction in comprehension and production, and the cognitive control mechanisms involved in this process. There is a long tradition of research on code-switching in the field of linguistics that studies the structural properties of code-switching, typically on the basis of linguistic corpora (for reviews, see Bullock & Toribio, 2009; Isurin, Winford, & De Bot, 2009). These corpus-based studies have yielded valuable theories on structural aspects of code-switching (some of which will be discussed below), but largely remained silent on the psychological and neural underpinnings.

On the other hand, cognitive and neurocognitive studies examining switching between languages have mainly focused on the processing of a series of single, unrelated items (e.g., unrelated words, digits, or pictures) rather than switching between languages in a meaningful utterance (e.g., a sentence). In these studies bilinguals are presented with isolated items that switch between languages across

trials (in comprehension tasks) or bilinguals must change the language of their response across non-switch and switch trials (in production tasks); for reviews, see Bobb and Wodniecka (2013) and Abutalebi and Green (2008). As will be discussed in the next section, these studies show that switching between languages incurs a measurable processing cost that is often asymmetric, i.e., larger when switching from the second language (L2) into the first language (L1) than vice versa.

An emergent body of studies seeks to examine the cognitive and neural correlates of language switching in more naturally occurring situations: switching within meaningful sentences, i.e., intra-sentential code-switching. In this chapter we will review in particular cognitive and neurocognitive studies on intra-sentential code-switching (for studies on inter-sentential code-switching, see, e.g., Gullifer, Dussias, & Kroll, 2013; Ibáñez, Macizo, & Bajo, 2010). We will also discuss studies that address the question of *why* code-switching occurs and what the cognitive and neural mechanisms are that drive bilinguals to switch into the other language. We will finally review studies that investigated the cognitive underpinnings of a corpus-based linguistic theory of code-switching, namely the triggering theory originally proposed by Clyne (e.g., 1967; 2003). Together these studies attest to the value of integrating linguistic, psycholinguistic and neurocognitive approaches to gain more insight into the neural and cognitive mechanisms of intra-sentential code-switching in comprehension and production, and into cross-language interaction processes in sentence comprehension and production more generally.

Psycholinguistic and neurocognitive studies often focus on externally induced switches, i.e., non-spontaneous language switches where bilinguals switch languages prompted by an external cue or respond to an externally generated switch (for exceptions, see Broersma, 2011; Gollan & Ferreira, 2009; Kootstra, van Hell, &

Dijkstra, 2010). Corpus studies, on the other hand, reflect internally generated switches in natural discourse. Both externally induced switches and internally generated switches enable researchers to address different questions related to language switching that in concert will advance our understanding of one of the most fascinating instances of cross-language interaction (for an excellent discussion, see Gullberg, Indefrey, and Muysken, 2009).

Before reviewing the literature on intra-sentential code-switching, we will first briefly discuss empirical studies and theoretical perspectives on language switching in the production and comprehension of unrelated items presented in isolation, on which the current psychological and neurocognitive models of language switching and cognitive control are predominantly based (cf., Green & Abutalebi, 2013).

Language switching costs when switching between single stimuli

In a seminal language-switching study, Meuter and Allport (1999) asked bilinguals to name a series of single digits alternating between their first language (L1) and second language (L2). The digits were presented one at a time against a colored background, and the color cued the response language (either L1 or L2). Language switches could occur from L1 into L2, or vice versa, and were unpredictable. The bilinguals were either L1 or L2 speakers of English, and spoke one of five other languages (French, German, Italian, Portuguese, or Spanish). The results showed that naming latencies on the switched trials (in which the response language changed from that used in the previous trial) were slower than on the non-switched trials. Interestingly, the language switching costs (defined as the latency difference between the switched and non-switched trials) were asymmetrical: switching costs

were larger when switching from the weaker language, L2, into the dominant language, L1, than when switching from the dominant L1 into the weaker L2. Since the publication of Meuter and Allport's study, numerous studies examined language switching effects in the naming of single items in unbalanced bilinguals and multilinguals, using behavioral (e.g., Costa, Santesteban, & Ivanova, 2006; Jiang & Forster, 2001; Linck, Schwieter, & Sunderman, 2013; Philipp, Gade, & Koch, 2007; Schwieter & Sunderman, 2008) and neurocognitive (e.g., Christoffels, Firk & Schiller, 2007; Jackson, Swainson, Cunnington, & Jackson, 2001; Verhoef, Roelofs, & Chwilla, 2009) techniques. These studies overwhelmingly report switching costs (which parallels basic findings in the more general task-switching literature; for a review, see Kiesel et al., 2010). Moreover, most studies replicated the finding that switching is most costly when switching from the weaker L2 into the dominant L1 (for more details, see reviews of behavioral (Bobb & Wodniecka, 2013) and neurocognitive (Van Hell & Witteman, 2009) studies).

Studies examining the reading of language-switched versus non-switched series of words have also observed switching costs. In contrast to the naming studies, however, the effects in the reading studies are less conclusive with respect to the asymmetry in switching costs: some studies observed that switching costs are not modulated by switch direction (Jackson, Swainson, Mullin, Cunnington, & Jackson, 2004, Event-Related brain Potential (ERP) data; Macizo, Bajo, & Paolieri, 2012), or are asymmetrical, with larger costs when switching from L2 into L1 (Chauncey, Grainger, & Holcomb, 2008 (N400); Litcofsky, Midgley, Holcomb, & Grainger, 2009), or when switching from L1 into L2 (Alvarez, Holcomb, & Grainger, 2003; Chauncey, Grainger, & Holcomb, 2008 (N250); Jackson et al., 2004, behavioral data).

For example, Jackson et al. (2004) had native English speakers with French, German, or Spanish as their L2 perform a parity judgment task on number words. Bilinguals were presented with a series of single number words in L1 or L2, and had to decide whether the number word was odd or even by pressing one of two buttons. Behaviorally, an asymmetric switch cost was found where it was harder to switch into L1 than L2, but ERP data did not yield clear switching effects in the components typically associated with language switching (including the N2, N400, and Late Positive Complex (LPC)). Later ERP studies measured switching of visually presented words (Alvarez et al., 2003; Chauncey et al., 2008; Litcofsky et al., 2009). In the switching condition, Alvarez et al. (2003) presented native English speakers who were beginning learners of Spanish with single words in L1 or L2 (in mixed lists) that on the previous trial were preceded by its translation (e.g., perro-dog). Using a go/no-go semantic categorization task, where participants were instructed to only press a button when the word referred to a body part, they observed that language switches resulted in a slightly larger N400 when switching into L1, but stronger later effects when switching into L2. In contrast to Alvarez et al. (2003), Chauncey et al. (2008) used unrelated prime-target pairs, and the targets were preceded by masked primes (i.e., briefly presented primes). Testing moderately proficient bilinguals, Chauncey et al. (2008) observed a larger N400 for switch as compared to non-switch trials when switching into L1, but a larger N250 modulation when switching into L2. Finally, in a mixed-language lexical decision task where English-French bilinguals were presented with a series of L1 English words, L2 French words, and non-words, and had to decide if the item was a word in either of their languages, Litcofsky et al. (2009) observed a larger N400 switching cost when switching into L1 as compared to non-switch trials, but no N400 modulation when switching into the L2. These ERP

comprehension studies show variation in the response to language switching that may depend on the nature of the task (priming vs. lexical decision) and proficiency of the bilinguals (beginning learner, moderately proficient, or immersed learner).

The evidence discussed so far is based on externally induced switches, as is typical in the aforementioned language switching studies. Switching costs have also been observed in the absence of experiment-induced cues, when switching was under the voluntary control of the bilingual in a picture naming task (Gollan & Ferreira, 2009). The observation that both voluntary (internally generated) switching and forced (externally induced) switching of isolated items are associated with measurable switching costs is important. As will be discussed below, forced single-item switching engages cognitive processes related to language control and inhibition. Voluntary single-item switching, on the other hand, bears more similarity to spontaneous code-switching in natural discourse.

Finally, under certain conditions, language switching costs have been found to be similar in both switching directions. Specifically, switching costs tend to be symmetrical when bilingual speakers are about equally proficient in L1 and L2 (e.g., Costa & Santesteban, 2004; Costa et al., 2006; Meuter & Allport, 1999). Symmetrical switching costs have also been found in unbalanced bilinguals when given a pre-language cue that provided sufficient time to prepare for the subsequent naming response, which could be a language switch or not (Verhoef, Roelofs, & Chwilla, 2009).

The dominant account to explain language switching costs is based on the Inhibitory Control model (Green, 1998); alternative explanations distinguish between endogenous and exogenous attentional control (Verhoef et al., 2009), or emphasize differential language activation rather than inhibition (e.g., La Heij, 2005), the speed

of response availability (Finkbeiner et al., 2006), or the persisting activation of L2 rather than the persisting inhibition of L1 (e.g., Phillip et al., 2007). The Inhibitory Control model proposes that for successful performance in one language, bilinguals employ a general cognitive mechanism, inhibitory control, to actively inhibit their other language. The model states that language task schemas, part of a general language control system that is external to the bilingual lexico-semantic system, control language actions. These language task schemas either activate or inhibit lemmas in the lexico-semantic system that are tagged for language-specific information. For example, when a bilingual speaks or reads in the weaker L2, the L2 task schema has to suppress the L1 task schema and inhibit the L1 lemmas in the lexico-semantic system. When a speaker switches into the other language, the task schema that is currently active has to be suppressed and the previously inhibited task schema needs to be reactivated, and this results in a language switching cost (see for a related account in terms of Task Set Inertia, Meuter & Allport, 1999). The Inhibitory Control model predicts that switching into the L1 would yield larger switching costs than switching into the L2, because the dominant language L1 needs to be inhibited more strongly during L2 processing than the weaker L2 needs to be during L1 processing. So when the switch goes from L2 to L1, the L1 has been strongly suppressed and thus requires more time to be reactivated than in the case of switching from L1 to L2. Indeed, the above review of isolated item switching studies indicated that most studies testing bilinguals who were more proficient in their L1 than in L2 found that switching into L1 was more costly than switching into L2. The Inhibitory Control model would further predict that when bilingual speakers are equally proficient in the two languages, the inhibition of one language is not more effortful than the inhibition of the other language. Instead, switching costs should be similar in

the two switching directions, which has indeed been observed (e.g., Costa & Santesteban, 2004; Meuter & Allport, 1999).

In sum, the language switching studies that examined the switching between a series of single, unrelated items (words, digits, pictures) overwhelmingly show that switching is associated with a measurable cost, observed in both behavioral and neurocognitive measures. Moreover, of the studies that examined switching in both directions, the large majority shows that switching from the L2 into the L1 is more costly than vice versa. Most studies explain these findings in terms of inhibitory control: switching into L1 is more costly because it is more effortful to suppress L1 during L2 processing.

A critical question the single-item switching studies raise is which insights they provide into the switching between languages within a meaningful utterance, like a sentence. The cognitive and neural mechanisms underlying successful switching between single, unrelated items pertain to the control and inhibition of languages, and keeping languages apart. Intra-sentential codeswitching, on the other hand, requires the integration of two languages to form a semantically and syntactically coherent utterance. Does keeping two languages apart, as needed in single-item switching, lead to different switching patterns than integrating two languages, as needed in intra-sentential codeswitching? For example, are switching costs, and the observation that switching into the L1 is more costly than switching into the L2, specific to single-item switching tasks, or are similar switching costs (and asymmetries in switching costs) associated with intra-sentential codeswitching? In the next section, we will review behavioral and neurocognitive studies that examined intra-sentential switching.

Switching costs in intra-sentential code-switching

Psycholinguistic and neurocognitive studies on intra-sentential code-switching show that, in general, switching languages within a sentence takes time and is more effortful relative to processing single-language sentences, in line with costs observed in switching between single, unrelated items. In an early study, Altarriba, Kroll, Sholl, and Rayner (1996) compared the silent reading of mixed language sentences (e.g., ‘He wanted to deposit all of his *dinero* at the credit union’) with single language sentences (e.g., ‘He wanted to deposit all of his money at the credit union’) in Spanish-English bilinguals, using eye-tracking technology. The sentences were always presented in the L2 English, and the switched target word was in L1 Spanish. The eye movement data showed that first fixation times were longer on switched words than on non-switched words. In a second experiment, the sentence contexts were presented visually word-by-word, and bilinguals were asked to name the target presented in uppercase letters. In line with the eye-tracking data, switched words took longer to name than non-switched words. This pattern of intra-sentential switching costs parallels basic findings in the unrelated, single-item language switching literature discussed above.

The next question is which cognitive or neural mechanisms drive these intra-sentential switching costs, and one way to gain more insight into this question is to examine which factors modulate switching costs. In other words, is intra-sentential code-switching less effortful in some bilingual speakers than in others, or less costly in specific linguistic situations? In the remainder of this chapter we will review intra-sentential code-switching studies that examined these issues in comprehension or production, using behavioral and neurocognitive techniques. We will also review experimental studies that studied the modulation of switching costs to test selected theories of code-switching that were developed in linguistics and based on corpus

data. We will conclude the chapter with a review of neuroimaging studies exploring brain areas that subserve language switching.

In a groundbreaking study, Moreno, Federmeier, and Kutas (2002) used ERPs to compare intra-sentential language switches with within-language lexical switches as English-Spanish bilinguals read for comprehension. They sought to examine whether language switches incur a cost at the lexical level of word recognition and lexical-semantic processing, or whether switches were essentially unexpected events at the level that affect later decision making stages (cf. Thomas & Allport, 2000) rather than at the lexico-semantic level. Moreno et al. argued that if language switching incurs a cost at the level of lexical access and semantic integration, language-switched words should elicit an increased N400 response (the ERP component that indexes lexical-semantic integration, Kutas & Federmeier, 2000). On the other hand, if bilinguals perceive a language switch as an unexpected event and a change in form rather than meaning, language-switched words should evoke an enhanced late positivity (LPC, an ERP component indexing sentence-level integration (Kaan, Harris, Gibson, & Holcomb, 2000), re-analysis (e.g., Friederici, 1995) or restructuring (Kolk & Chwilla, 2007) or the processing of unexpected or improbable events (e.g., Coulson, King, & Kutas, 1998; McCallum, Farmer, & Pockock, 1984)). Highly proficient English-Spanish bilinguals read sentences in L1 English, while ERPs were recorded, where the sentence-final word was either a code-switch into L2 (e.g., “Each night the campers built a *fuego* [fire].”), a lexical switch (e.g., “Each night the campers built a *blaze*.”), or no switch (e.g., Each night the campers built a *fire*.”). The sentences were either regular sentences (as the previous example) or highly-constraining idioms (e.g., “Out of sight, out of [*mente* (code-switch), *brain* (lexical switch), *mind* (no switch)]”). Lexical switches resulted in an N400 in both

regular and idiomatic sentences. Code-switches resulted in an N400 in the regular sentences, but not in the highly-constrained idioms; the N400 effect in the regular sentences had a left, frontally skewed distribution, which is not a typical N400 distribution. Finally, a switch-related modulation was observed in the LPC, in both regular sentences and highly-constrained idioms. Subsequent regression analyses to examine the influence of L2 proficiency on these switches showed that higher L2 Spanish proficiency was associated with earlier peak latency and smaller amplitude of the LPC to code-switches, whereas individuals who were L1 English-dominant showed greater N400 amplitudes and earlier onsets for within-language switches. These findings suggest that code-switched words are processed differently from within-language lexical switches. Moreno et al. (2002) interpret the absence of an unequivocal N400 modulation in code-switched versus non-switched sentences to imply that switching costs do not incur a cost in the lexical-semantic integration of the switched word into the sentence. Rather, bilinguals may treat a code-switch as an unexpected event at a nonlinguistic level. This would support the idea that language switching costs arise from outside the bilingual lexico-semantic system, and originate from competition between task schemas that coordinate the output of the lexico-semantic system with the response task. Finally, the finding that bilinguals with higher proficiency in L2 showed an earlier peak latency and a smaller amplitude of the LPC suggests that these more proficient bilinguals noticed the language switch earlier and experienced the switch as less unexpected.

Proverbio, Leoni, and Zani (2004) examined the neural correlates of intra-sentential code-switching in eight Italian-English simultaneous interpreters, a unique population of highly proficient individuals who use and switch between their languages as part of their job. These interpreters read incomplete sentence frames,

which began in either L1 or L2 (e.g., ‘Global market is facing serious’), and was followed by a sentence-final word about 3200 ms later that was either a code-switch into the other language (here: ‘problemi’) or a word in the same language that could be semantically congruent or incongruent with the sentence frame. The interpreters were instructed to read the sentences and target words, and decide whether the final word was a sensible completion of the sentence. The different sentence-target conditions were presented in separate blocks, so the language switches were completely predictable. A group of eight Italian monolinguals also read the Italian versions of the semantically congruous and incongruous sentences, and showed an N400 effect. Interpreters showed a similar N400 to the incongruity that was larger in code-switched sentences than non-switched sentences. No switch-related modulation of the LPC was observed. With respect to language switching directions, the N400 was larger when switching from the dominant L1 into the weaker L2 than when switching from L2 into L1. The behavioral data also showed that switching into the weaker L2 was more costly. Interestingly, this switching asymmetry in meaningful sentences is in the opposite direction as the switching asymmetry typically observed in the single, unrelated item switching studies.

The Moreno et al. (2002) and Proverbio et al. (2004) studies show that intra-sentential code-switching incurs a processing cost in the form of a modulation of the N400 and LPC (Moreno et al., 2002), or the N400 only (Proverbio et al., 2004). So even when bilinguals could fully predict the occurrence of a language switch, as in Proverbio et al., a switch-related modulation of the N400 was observed. However, because of substantial differences in the experimental methodology between these two sentential code-switching studies (e.g., predictability of code-switches, sentence presentation, instructions, type of bilinguals), it is difficult to compare these results.

Nonetheless, these two studies do indicate that the N400 and LPC are critical ERP components that are associated with comprehending code-switched words embedded in meaningful sentence.

These early studies are not without some methodological concerns. First, both studies used both cognates (i.e., words that have a similar orthography, phonology, and meaning across languages, like ‘problemi-problems’) and noncognates as critical target words, but it remains unclear whether this factor was explicitly controlled. Given the large literature showing that cognates and noncognates are processed differently in both comprehension and production (e.g., see Van Hell & Tanner, 2012, for a review), it is possible that the effects of intra-sentential code-switching are confounded with bottom-up lexical effects related to cross-language activation. Specifically, using a cued picture naming switching task in German-English bilinguals, Declerck, Koch, and Philipp (2012) found that switching between German and English yielded smaller costs when the items were pictures of cognates or when they were digits (which included many cognates) compared to non-cognate pictures. This suggests that the co-activation of the cognates’ phonology across two languages reduces the switching costs associated with cognate items.

Second, Proverbio et al. (2004) examined the effect of code-switching in the context of semantically anomalous sentences, which may have confined their effects to the N400 component. Third, Proverbio et al. (2004) presented the sentences in such a way that may have distorted natural processing. Namely, the sentence (minus the final word) was presented in its entirety for 1800 ms (and an inter stimulus interval (ISI) between 1400-1500 ms), followed by the critical final word for 250 ms. The singling out of the critical word may have brought extra attention to the code-switch, in addition to encouraging the use of strategic behavior as opposed to natural reading.

Fourth, in Proverbio et al. the code-switched sentences and the non-switched sentence were presented in blocked lists (and the code-switched sentences were also blocked by switching direction) and thus predictable, whereas in Moreno et al. the switched and non-switched sentences were presented in mixed blocks and thus unpredictable. As the LPC is associated with the processing of unexpected or improbable events (e.g., Coulson et al., 1998; McCallum et al., 1984), variations in mere predictability incurred by blocked vs. mixed presentations may have resulted in an absence of an LPC in Proverbio et al. (2004) and the presence of an LPC modulation in Moreno et al. (2002).

Finally, in both studies the code-switches always appeared at the sentence-final word, and processing of the sentence-final word is possibly confounded with sentence-general wrap-up processes. The LPC component is highly similar to the P600 component, and the P600 has been associated with sentence-level integration and re-analysis (e.g., Friederici, 1005; Kaan, Harris, Gibson, & Holcomb, 2000) or restructuring related to monitoring and executive control (e.g., Kolk & Chwilla, 2007). Brain activity associated with code-switched words when presented as final-sentence words may not only reflect language switching per se, but also processes related to sentence reanalysis, reintegration and restructuring. This may also explain why the highly proficient interpreters tested in Proverbio et al. (2004) did not show an LPC, but the less proficient bilinguals tested in Moreno et al. (2002) did: integrating and reanalyzing language-switched sentences may be less effortful for interpreters as they are professional trained to switch between languages. As will be discussed below, two recent intra-sentential code-switching studies disentangled L2 proficiency and bilinguals' frequency of code-switching in everyday life.

Building upon Moreno et al. (2002) and Proverbio et al. (2004), Van der Meij, Cuetos, Carreiras, and Barber (2011) investigated the influence of L2 proficiency on intra-sentential code-switching using ERPs, while addressing some of the methodological concerns of the earlier studies. Their bilinguals were native Spanish speakers who had learned their L2 English at school, and were divided into higher and lower proficiency speakers (mean score self-reported speaking, listening, and reading skills high proficiency speakers: 7.9; mean score low proficiency speakers: 6.0; scale from 1 (almost none) to 10 (native speaker)). The Spanish-English bilinguals read sentences in L2 English that either contained a (one-word) code-switched sentence-medial adjective or a non-switched control word. The adjectives were all non-cognates, and the sentences were presented in mixed lists. Sentences were only presented in L2 English and the switched word was always in L1 Spanish. Both higher and lower proficiency bilinguals showed an enhanced N400 and LPC (both larger in the high proficiency group) to code-switched words. Additionally, both groups showed an early negativity that may be related to orthographic processing (left occipital N250) and a lasting frontal positivity that may be the onset of the LPC. In the higher proficiency bilinguals, the switch-modulated N400 effect extended to left anterior electrodes, suggestive of a LAN, as has also been observed by Moreno et al. (2002). The Van der Meij et al. (2011) study shows that switching of words midway in the sentence incurs switch-related modulations of both the N400 and the LPC, in line with Moreno et al. (2002), indicating that code-switched words elicit both lexico-semantic integration costs, as well as more sentence-level updating and reanalysis costs. Though neither study examined code-switching in both language switching directions, together they suggest that switch-related biphasic N400-LPC responses

can occur when switching from L1 into L2 (Moreno et al., 2002) and when switching from L2 into L1 (Van der Meij et al., 2011).

Litcofsky and Van Hell (in preparation; Litcofsky, 2013) examined intra-sentential code-switching in both language switching directions in Spanish-English bilinguals, in a behavioral study (self-paced reading; Experiment 1) and ERP studies (Experiments 2 and 3). The bilinguals tested in Experiments 1 and 2 were habitual code-switchers, and reported to frequently code-switch in their everyday life. They were living in an L2 English environment (USA), and a series of subjective and objective proficiency measures (including the Boston Naming task, a lexical decision task, a self-paced sentence reading task, and self-rated proficiency, all in both languages) indicated that they were nearly equally proficient in their two languages. The bilinguals read sentences that began in Spanish or English and could contain a sentence-medial, full code-switch into the other language (e.g., “Each year, the shopkeeper makes his own *juguetes para los niños pequeños*.”) or not (“Each year, the shopkeeper makes his own toys for the young children.”). The sentences were presented in mixed lists, so the code-switches were unpredictable, and all words prior to the code-switch and the first code-switched word were non-cognates. The behavioral self-paced reading study showed that the first code-switched word and the three subsequent words, as compared to non-switched words, were read more slowly, but that this switch cost only appeared when switching from the dominant into the weaker language, not vice versa. The ERP study, testing a new group of bilinguals from the same population, corroborated the behavioral findings. The ERPs revealed a late positivity (LPC) in response to code-switched words, but only when switching from the dominant into the weaker language, and not vice versa. No switched-related modulation of the N400 was observed.

To examine to what extent the absence of a switch-related N400 was related to the high proficiency level of these bilinguals, a new group of Spanish-English bilinguals was tested (Experiment 3) who were less proficient in their L2 (mean self-reported proficiency, out of 10, in speaking, listening, and readings ranged from 7.5-8.7); these ratings are comparable to the high proficiency Spanish-English bilinguals tested in Van der Meij et al. (2011)). All Spanish-English bilinguals were immersed in their L1 (they all lived in Spain), and similar to the participants tested by Van der Meij et al. (2011), they did not code-switch regularly in their everyday life. If code-switching incurs a cost at the level of lexical access and semantic integration (as indexed by the N400), these lower proficiency bilinguals may show a switch-related N400 modulation (as in the Van der Meij et al. study). The ERP data yielded no switch-related N400 effect. As in the ERP and behavioral experiments with the highly proficient bilinguals, these lower proficiency bilinguals' ERPs showed a late positivity (LPC) in response to the code-switched words, but only when the bilinguals switched from the dominant into the weaker language, and not vice versa. The observation that switching from the dominant language into the weaker language incurs larger behavioral and neural switching costs is thus consistent, and was observed both in highly proficient habitual code-switchers immersed in L2 and moderately proficient non-habitual code-switchers immersed in L1.

In conclusion, the emergent literature on the cognitive and neural correlates of intra-sentential code-switching is far from being conclusive, but together these first studies suggest some first patterns. The major ERP components that are associated with intra-sentential code-switching are the N400 (indexing switching costs related to lexico-semantic access and integration) and the LPC (indexing switching costs associated with sentence level integration and reanalysis, the processing of

unexpected task-related events, and restructuring processes related to executive control and monitoring). Assuming that particularly low proficient bilinguals or non-habitual code-switchers would experience more lexical-level integration difficulties (as indexed by the N400) than highly proficient bilinguals or habitual code-switchers, one would expect a switch-related modulation of the N400 to be more pronounced in the former than in the latter. However, the currently available evidence does not justify this assumption, as switch-related N400 effects have been found in bilinguals with different L2 proficiency levels, ranging from moderately proficient L2 classroom learners (Van der Meij et al., 2011) to highly proficient professional interpreters (Proverbio et al., 2004).

With the exception of Proverbio et al. (2004), all studies observed switch-related LPC effects. Although in Moreno et al. (2002) the switch-related LPC on the sentence-final word was possibly confounded with sentence wrap up effects, the mid-sentence code-switching studies (Van der Meij et al., 2011; Litcofsky & Van Hell, in preparation) confirm that these LPC effects reflect true code-switching processes that appear related to sentence-level integration and reanalysis, and were observed in moderately and highly proficient bilinguals and in habitual and non-habitual code-switchers. The absence of the LPC effect in Proverbio et al. (2004) is likely due to the fact that in this study switched sentences and non-switched sentences were presented in blocks, and code-switches were thus predictable, whereas in the remaining studies presentation of switched and non-switched sentences was mixed and code-switches were unpredictable. Variations in the predictability of code-switches impact code-switching costs, as has also been observed in the single, unrelated item language switching literature (for a review, see Bobb & Wodniecka, 2013).

Finally, those studies that tested switching in both directions (Litcofsky & Van Hell, in preparation; Proverbio et al., 2004), using both behavioral and ERP techniques, consistently found asymmetrical switching costs such that switching from the dominant L1 to the weaker L2 incurs higher switching cost than switching from the weaker L2 to the dominant L1, in the behavioral, as well as in the ERP data. This asymmetry is in the direction opposite to the asymmetry observed in the single, unrelated item switching literature where switching into L1 has found to be more costly. The latter finding is typically explained by the mechanism of inhibitory control stating that switching into L1 is more costly because it is more effortful to suppress L1 during L2 processing than the L2 during L1 processing. The currently available evidence on intra-sentential code-switching suggests that inhibitory control is not the cognitive mechanism underlying switching words within a meaningful sentence. Rather, when processing a meaningful sentence, bilinguals seek to integrate individual words into a coherent semantic and syntactic structure. This higher order integration of lexical items is fundamentally different from processing a series of isolated and unrelated items. When processing words in language-switched sentences, bilinguals do not rely on response inhibition in every single trial (as in processing a series of single, unrelated items). Rather, they may continuously adjust the level of activation of their L1 and L2 to optimize task performance by reducing the level of activation of L1 in order to facilitate language comprehension or production in L2, or vice versa. **1)** The fact that the pattern of behavioral and ERP effects intra-sentential code-switching was similar for habitual and non-habitual code-switchers suggests that this dynamic adjustment of activating L1 and L2 is more related to language proficiency rather than code-switching experience per se.

The intra-sentential code-switching studies reviewed above yield important information about the temporal unfolding of neural events associated with the different subprocesses of code-switching, and the locus of the code-switching costs. In the next section, we will discuss studies that sought to unravel the linguistic and cognitive mechanisms underlying code-switching by translating descriptive linguistic theories, often based on linguistic corpora, into predictive hypotheses that are tested in controlled experiments using psycholinguistic research techniques. We will discuss tests of one of these linguistic theories in more detail: the triggering theory.

Triggering and intra-sentential code-switching

The triggering hypothesis was first proposed by Clyne (e.g., 1967; 2003) who noted in his study on the language use of German, Dutch, Hungarian, Italian, Spanish, Croatian, and Vietnamese immigrants in Australia that code-switches tend to occur when a sentence contains one or more cognates (like ‘tennis’ in the example below). Clyne proposed that cognates, but also proper nouns and homographs, can function as triggers that facilitate a switch to the other language. For example, the Croatian-English cognate ‘tennis’ triggered a switch to English, in “Imam puno zadaca I sutra mi igramo *tennis* .. that’s about all” ([“I have a lot of assignments and tomorrow we are playing *tennis* .. that’s about all”]; Hlavac, 2000, as cited in Clyne 2003, p. 164). On the basis of his corpus research, Clyne (1967) further distinguished three triggering loci: sequential facilitation, where the code-switch takes place after the trigger, anticipational facilitation, where the code-switch takes place before the trigger, and a combination of these two, where the code-switch is surrounded by two trigger words. The mechanism of triggering nicely aligns with the ubiquitous finding that cognates co-activate a bilingual’s two languages, which then facilitate a switch to the

other language, although at the time Clyne (1967) first proposed the triggering theory, empirical evidence on lexical processing of cognates and the parallel activation of bilinguals' two languages was basically non-existent.

Clyne's work was based on examples of triggered code-switches in his corpus. Broersma and De Bot (2006) were the first to statistically test the triggering hypothesis in their corpus study. They analyzed several conversations in which three Moroccan Arabic-Dutch bilinguals code-switched, and coded both the code-switches and the cognates in each sentence. The results showed that code-switches were indeed more likely to occur after a cognate, especially if the cognate and the code-switch were in the same clause. They therefore proposed the adjusted triggering hypothesis, which states that a cognate can function as a trigger for a code-switch if both occur in the same clause. The adjusted triggering hypothesis integrates lexical triggering with bilingual language production models, and states that triggering occurs at the lemma level. The selection of the lemma of a trigger word, for example a cognate in Language X, activates not only words in Language X, but also words in Language Y. This leads to an increase in the activation level of Language Y, which makes it more likely that the speaker will select lemmas from Language Y in the course of the utterance.

Subsequent analyses of natural speech corpora of Dutch immigrants in New Zealand and Australia (Broersma 2009; Broersma, Isurin, Bultena, & De Bot, 2009) and of Russian immigrants in the USA (Broersma et al., 2009) corroborated the earlier findings that code-switches occur more frequently in clauses containing a cognate than in clauses not containing a cognate, even in typologically-related languages like Dutch and English which contain a high proportion of cognates.

Broersma et al. (2009) also observed that interlingual homophones (words in two languages that share phonology but not meaning) sometimes served as triggers.

These corpus studies provide important quantitative evidence for the co-occurrence of trigger words and code-switches, but in order to gain more insight into the processing mechanisms underlying triggered code-switching, these off-line counts need to be validated by experimental research that allows for specific manipulations of critical variables and a more systematic control of potentially modulating factors (cf. Gullberg, Indefrey, & Muysken, 2009). Kootstra, van Hell, and Dijkstra (in revision; Kootstra, 2012) examined the triggering hypothesis in a mimicked discourse situation in the lab, using the confederate-scripted priming technique. In this technique, two participants perform a task, but (unbeknownst to the ‘true’ participant) one of them is actually a confederate who is instructed by the experimenter and whose language behavior is scripted, in this case to produce code-switched or non-switched (one language) sentences. Dutch-English bilingual ‘true’ participants interacted with the Dutch-English bilingual confederate, and described pictured events to each other (e.g., a picture of a hunter putting a rose on a chair). The patient object in the picture was a cognate (e.g., rose-roos), a false friend (e.g., rock-rok [skirt]), or a non-cognate control word that did not overlap in form or meaning across languages (e.g., bike-fiets). The confederate was scripted to code-switch, directly after the critical patient trigger (i.e., the cognate or false friend) or non-trigger (non-cognate control word), in half of the picture descriptions (e.g., ‘De jager legt de roos on the chair’ [The hunter puts the rose on the chair’]), and the other half were not code-switched. After the true participant had selected the correct picture from one of two pictures on the screen (which was the cover task), the true participant described the next pictured event on the screen (e.g. a grandma putting a baby on a chair). The patient objects in the

participants' pictures were cognates, false friends, or non-cognate control words, as in the confederate's pictures. Participants were free to use Dutch or English in their description, and were not forced to code-switch.

The critical question was whether participants would code-switch more often in their picture description when their picture contained a lexical trigger (cognate or false friend) relative to a non-trigger, and to what extent the participants' likelihood to code-switch was influenced by the confederate's switched or non-switched utterance in the previous trial. It appeared that participants switched more often when their picture contained a cognate or a false friend than when it contained a non-trigger control word, but this effect only emerged when the confederate had switched in the previous trial. This finding indicates that lexical triggering of code-switches only occurs when there is already a high tendency to code-switch in a discourse situation (here when the interlocutor has just code-switched). This qualifies the lexical triggering hypothesis and suggests that lexical triggering in free code-switching in language production is not a basic psychological mechanism that is impervious to contextual information, but is restricted to these discourse situations in which code-switching is quite frequent.

In another study, using the structural priming technique, noun cognate lexical triggers were found to boost the priming of code-switches (Kootstra, Van Hell, & Dijkstra, 2012). Dutch-English bilinguals were asked to repeat a code-switched primed sentence that started in L1 Dutch and switched into L2 English (e.g., *De jongen gooit een bal to the butcher* [The boy throws a ball to the butcher]), and subsequently describe a target picture (e.g., of a boy throwing a ball to a diver) by means of a sentence that switched from L1 Dutch to L2 English. The object noun in the prime sentence (here: ball) was either a cognate or a noncognate and was repeated

or not repeated in the target sentence. Two groups of Dutch-English bilinguals were tested: a group of highly proficient bilinguals and a group of moderately proficient bilinguals. Analyses of the switch location in the target sentence showed that bilinguals were more likely to switch at the same position as in the prime sentence when the noun object was a cognate and when it was repeated across prime sentence and target picture. These cognate triggering and lexical repetition effects were more pronounced in the highly proficient bilinguals than in the moderately proficient bilinguals. This study shows that cognate lexical triggers enhance the likelihood that the switch location in a spoken sentence aligns with the switch-location in a previously encountered utterance, and thus provides converging evidence that cognate (noun) triggers can affect code-switching.

Further evidence for the impact of cognate triggering on the production of switches comes from a picture naming study in which Dutch-English bilinguals had to name a series of pictures that were preceded by a phonologically similar cognate (e.g., sock-sok) or a non-cognate picture (Broersma, 2011). The crucial items were the pictures following the cognate and noncognate pictures. Bilinguals were either required to switch from L1 into L2 or vice versa (as indicated by a color cue; Experiment 1) or were free to switch as long as they switched about half the time (Experiment 2). Bilinguals switched faster after cognates than after noncognates in the cued condition (in both switching directions), and switched more often after cognates than after noncognates in the free switching condition (but only when switching from L1 into L2).

The experimental studies discussed so far used nouns as cognate triggers. Two recent studies using verb cognate triggers suggest that triggering effects are restricted to nouns, at least in languages in which cognate verbs rarely fully share orthography

and phonology. Using a shadowing task, Bultena, Dijkstra, and Van Hell (in revision) examined whether verb cognates could modulate switching costs. Dutch-English bilinguals were presented with code-switched sentences that started in L1 Dutch and switched into L2 English, or vice versa. The code-switch was preceded by a verb cognate (e.g., De ervaren schilders schetsen the flowers from a distance [The experienced painters sketch the flowers from a distance]) or a verb noncognate (e.g., De ervaren schilders tekenen the flowers from a distance [The experienced painters draw the flowers from a distance]). As soon as bilinguals heard the beginning of the sentence, they were asked to reproduce the incoming signal and repeat ('shadow') what they heard as quickly and as accurately as possible. The shadowing task allows for the measurement of the delay between word onset in the original recording and the participant's reproduction of the word. Shadowing latencies showed that switching from L1 into L2 was more costly than switching from L2 into L1, thereby replicating the ERP studies by Proverbio et al. (2004) and Litcofsky & Van Hell (in prep). However, the switching costs were not modulated by the preceding verb cognate, indicating that shadowing a verb cognate trigger did not facilitate the shadowing of the subsequent code-switch. Such an absence of a verb triggering effect was observed in both switching directions, and in the two syntactic structures that were tested in the study (i.e., word order that is shared (SVO) or not shared (XVSO) across Dutch and English).

These findings were paralleled in a follow-up study (Bultena, Dijkstra, & Van Hell, accepted), using the self-paced reading variant of the moving window paradigm (Just, Carpenter, & Woolley, 1982). Two new groups of Dutch-English bilinguals who varied in L2 proficiency were visually presented with code-switched sentences (i.e., the above SVO sentence materials). The self-paced reading times showed a

switching cost for switching from L1 into L2, but not vice versa; the switching costs into L2 were smaller as L2 proficiency increased. Importantly, reading a verb cognate trigger directly preceding the code-switch did not modulate the switching cost.

In his original writing, Clyne had observed that triggers do not necessarily have to be lexical, and noted that if the context was a typical, for example, Australian context, speakers were more likely to switch into the language of this context, here English. In the example described below, a German native speaker who worked in an Australian setting was asked about his occupation, and Clyne argued that this work situation triggered a switch into English. ‘*Well, wir müssen zuerst sagen, was wir sind von Beruf an und für sich und was what we are doing daily, more or less is that right?*’ ([*Well, we first have to say what our occupation is and what*] *what we are doing daily, more or less is that right?*’); Clyne, 1967, p. 90. In a series of three experiments, Van Hell, Sánchez-Casas, & Ting (in preparation) studied whether switching costs are modulated when preceded by a socio-contextual cue. Participants first read a sentence containing a socio-contextual cue that was either congruent with the language of the code-switch (e.g., Women in *Valencia* are incredibly stylish. Their *cabello* [hair] is always cut fashionably) or not congruent with the language of the code-switch (e.g., Women in *Chicago* are incredibly stylish. Their *cabello* is always cut fashionably). Three groups of Spanish-English bilinguals participated: highly proficient Spanish-English bilinguals tested in Central Pennsylvania (habitual code-switchers immersed in their second language), highly proficient Spanish-English bilinguals tested in El Paso, close to the US-Mexican border (habitual code-switchers living in an environment where both languages were spoken), and moderately proficient Spanish-English bilinguals tested in Spain (non-habitual code-switchers immersed in their first language; this population is similar to the Dutch-English bilinguals tested in a similar

study by Witteman and Van Hell (2008), as discussed in Van Hell and Witteman, 2009). It appeared that code-switches were read faster when preceded by a congruent socio-contextual cue than by a non-congruent cue, but this effect was most pronounced in the highly proficient Spanish-English bilinguals tested in El Paso, who were habitual code-switchers immersed specifically in a context where both languages were used. This suggests that socio-contextually congruent cues can facilitate the comprehension of code-switched sentences, and that this effect seems particularly strong in habitual code-switchers who live in a bilingual environment.

In conclusion, although the quantitative analyses of corpus studies suggest that lexical triggers co-occur with code-switches in a wide variety of situations involving different types of bilingual speakers, the experimental studies indicate that lexical triggering per se is not a basic cognitive mechanism that facilitates or leads to code-switching in all circumstances. Rather, in a language production situation where bilinguals were free to code-switch (or not), cognates or false friends only triggered a code-switch to the other language when the speaker's discourse partner had just code-switched (Kootstra et al., in revision; Kootstra, 2012), suggesting that lexical triggering is restricted to discourse situations in which code-switching occurs frequently. Importantly, this discourse situation may mimic the contextual situation in which linguistic corpora are collected, suggesting that quantitative analyses of code-switches in corpora may reflect code-switching behavior in specific discourse situations, but do not necessarily provide a window onto the cognitive underpinnings of code-switching in speakers or listeners/readers.

Furthermore, the available evidence suggest that lexical triggering effects are restricted to nouns (both cognates and false friends), and that the cognate verbs do not

facilitate a code-switch to the other language, at least not in languages where cognate verbs rarely fully share orthography and phonology.

Brain areas subserving language switching

In addition to behavioral and electrophysiological investigations of language switching, in recent years neuroimaging has been used to examine the neural substrates underlying language switching. In the large majority of these studies bilinguals have been presented with a series of unrelated, isolated items (for a review, see Luk, Green, Abutalebi, & Grady, 2012). Although very few studies examined the switching of words embedded in a meaningful linguistic context, combining the outcomes of these studies with the isolated item switching studies may yield some first insights into the neural mechanisms underlying switching.

Mariën, Abutalebi, Engelborghs, and Deyn (2005) sought to identify the neural correlates of language switching and language mixing by examining the correlates of pathological language switching and pathological language mixing. Pathological language switching is defined as uncontrolled switching between multiple languages within the course of the same sentence, whereas pathological language mixing is defined as uncontrolled switching of languages across sentences. EM was a 10-year old English-Dutch bilingual who suffered from two strokes, resulting in vascular acquired aphasia in both English and Dutch. Mariën and colleagues reported computerized tomography, magnetic resonance imaging, and single-photon emission computed tomography data from EM. While damage was observed to the left frontal cortex, left temporo-parietal areas, left caudate nucleus, and left thalamus, both the pathological switching and mixing subsided upon reperfusion of the left frontal cortex and left caudate nucleus. This pattern of behavior

supports the neuroanatomical device response Fabbro et al. (1997) proposed for controlling language selection, which involves a number of brain regions otherwise associated with general cognition and executive control. Specifically, it appears that the proposed articulatory anterior cortical-subcortical loop is also involved in the selection of items from the target language via inhibition of items from the non-target language.

Androver-Roig et al. (2011) reported the clinical and neuroimaging data from a bilingual individual with aphasia. JZ was a 53-year old Basque-Spanish bilingual who suffered from a hematoma in the left basal ganglia. Like EM in Mariën et al. (2005), JZ acquired bilingual aphasia following the trauma. However, JZ's aphasia impacted his languages to different degrees. JZ's first language, Basque, was more impaired than his second language, Spanish. By administering a series of neuropsychological tests, Androver-Roig and colleagues observed asymmetry in both production and translation. In particular, the Bilingual Aphasia Test (BAT; Paradis & Libben, 1987) revealed deficits in first language production, but intact production in his second language. Deficits were also found when JZ was asked to translate from his second language into his first language. In the Trail Making Task (TMT; Reitan, 1958), JZ was asked to connect together a series of randomly distributed twenty-five circles containing numbers and letters using paper and pencil. The TMT is considered an indicator of executive functioning processes, such as attentional awareness and visual scanning, and is often used to measure the severity of brain damage. JZ's poor performance on the TMT led researchers to believe that while poor first language lexical access could explain his asymmetric translation performance on the BAT, JZ's translation pattern could also be the result of a more domain general switching

impairment where bilingual aphasia presents as part of a larger impairment that encompasses linguistic and non-linguistic aspects of executive control.

Recent neuroimaging techniques have allowed researchers to investigate language switching in non-clinical populations. Abutalebi et al. (2007) used functional magnetic resonance imaging (fMRI) to study the neural correlates of language switching in Italian-French bilinguals who had greater exposure to French (because they lived in a French community in Switzerland). Participants passively listened to four stories in the scanner that contained unpredictable language switches from Italian to French or vice versa. Two of the stories contained regular switches, which occurred at the start of noun and verb phrases (e.g., *Il piccolo principe qui m'a posé beaucoup de questions* [The little prince who has asked me a lot of questions]), and two of the stories contained irregular switches, which occurred within noun and verb phrases (e.g., *Il piccolo prince était...* [The little prince was...]). The order of the stories was randomized among participants. The neuroimaging data showed that for regular switches into L1 Italian, the language of less exposure, there was increased activity across the left hemisphere, including the prefrontal, parietal, and temporal cortex, as well as in the anterior cingulate cortex, basal ganglia, and thalamus. Neural activity in the right hemisphere was observed in the prefrontal and temporal cortex, as well as the putamen. A similar pattern of activation was found for regular switches into L2 French, but the activation was notably less extensive. For irregular switches into Italian, the neuroimaging data showed heightened activation in the left inferior frontal gyrus, left parietal lobule, right inferior and middle frontal gyri, and right insula. Again, a similar pattern of activation was found for irregular switches into French.

Regular and irregular switches yielded different patterns of neural activation. Generally, regular switches resulted in activation of regions associated with lexical processing, including the inferior frontal gyrus – pars orbitalis (BA47). On the other hand, irregular switches resulted in activation of regions associated with phonological and syntactic processing, such as the opercular portion of Broca’s area and the left inferior parietal area. Abutalebi et al. interpreted the differences in neural recruitment as evidence for regular switches being treated like translation equivalents, or lexical alternatives, and irregular switches being treated like violations that require phonological and/or statistical analysis for successful comprehension.

Conjunction analyses on the neuroimaging data revealed a difference in neural activation by switch direction in the regular switches. Regular switches into L1 Italian as compared to L2 French activated the left caudate nucleus, the right supramarginal gyrus, and bilaterally, the anterior cingulate cortex and posterior cingulate cortex. Regular switches into L2 French as compared to L1 Italian activated the left superior parietal lobule, left anterior superior temporal gyrus, and the right temporal pole. Conjunction analyses also revealed a difference in neural activation by switch direction for irregular switches. Irregular switches into L1 Italian as compared to L2 French activated the left caudate head and the bilateral anterior cingulate cortex. Activation was also found in the left insula, left superior temporal gyrus, and right middle temporal gyrus. Irregular switches into L2 French as compared to L1 Italian activated the left superior frontal gyrus, left inferior parietal lobule, left precuneus, and the right precentral gyrus.

These results show that language switching recruits a large network of bilateral prefrontal and temporal associative regions with a dissociation in recruitment between switch types. The set of areas activated by irregular switching are the brain

regions typically recruited by syntactic and phonological processing, whereas the set of areas activated to regular switching are brain regions associated with lexical processing. Interestingly, switching into Italian, the native language which is also the language of less exposure, required brain areas typically associated with executive control and cognition. The researchers interpreted these findings as neural evidence of a switching cost in which the less-exposed language requires activation of cognitive control mechanisms and correlates in order for it to be activated successfully in a dominant-to-weak language switch.

Abutalebi and Green (2008) proposed a neurocognitive model of bilingual language switching, based on previous neuroimaging studies involving language switching and translation (see also Abutalebi & Green, 2007). The model consists of five brain regions: left dorsolateral prefrontal cortex, anterior cingulate cortex (ACC), caudate nucleus (a subcortical structure belonging to the basal ganglia), and bilateral supramarginal gyri. Abutalebi and Green posited that each of the brain areas in this subcortical-cortical network contribute distinct and complementary functions to negotiate the cognitive demands needed to successfully manage a bilingual's two languages during language switching. More specifically, the prefrontal cortex (involved in executive functions, response selection and inhibition, decision making, and working memory) works together with the ACC (involved in the detection of response conflict) and the basal ganglia for response inhibition, in particular, the inhibition of non-target language interference. According to their model, the ACC signals potential response conflict to the prefrontal cortex, and the prefrontal cortex biases against incorrect language selection. A more anterior part of the ACC withholds a response to the current language and the more posterior part of the ACC initiates a response to the relevant language. Abutalebi and Green further suggest that,

in case of unpredictable language switches, the left posterior parietal cortex may bias language selection away from the previous language and the right parietal cortex may bias language selection towards the current language. Parietal activity appears to be absent in case of predictable and expected language switches. Finally, Abutalebi and Green propose that the basal ganglia subserves language planning through a circuitry of left basal ganglia and left prefrontal cortex and/or works with the supplementary motor area (SMA) to inhibit a prepotent response.

A few years later, Luk, Green, Abutalebi, and Grady (2012) conducted a meta-analysis in order to evaluate Abutalebi and Green's (2008) bilingual subcortical-cortical network control network, using the Activation Likelihood Estimation (ALE) method (Eickhoff et al., 2009; Turkeltaub, Eden, Jones, & Zeffiro, 2002). They aimed to identify which neural regions show common activity in response to the cognitive control demands involved in bilingual language switching. The meta-analysis included ten studies that had employed either fMRI or positron emission tomography and a combined sample of 106 bilinguals. All but one study (Abutalebi et al., 2007) employed a single item switching task, where the switched items were not embedded in a meaningful linguistic context. Ten distinct neural clusters were identified that were largely left lateralized and frontal. Among these clusters were the bilateral caudate and the left prefrontal regions. While there was no significant engagement of the anterior cingulate cortex or the supramarginal gyri (unlike in Abutalebi and Green's 2008 model), the finding remains overall consistent with the argument that there is a frontal-subcortical circuit involved in language switching (Fabbro et al., 1997; Green & Abutalebi, 2008; see Green & Abutalebi, 2013, for a proposed set of neural correlates that underlie eight control processes in bilingual speech production). It also aligns with research reporting bilingual patients with aphasia who had lesions

in subcortical brain regions and exhibited pathological language switching (Androver-Roig et al., 2011; Mariën et al., 2005). As noted, these neural models are largely based on neuroimaging studies using single item switching tasks, but the proposed subcortical-cortical network provides a valuable basis for future neuroimaging studies examining code-switched utterances embedded in a meaningful linguistic context such as sentences.

Concluding remarks

Intra-sentential code-switching is a hallmark of bilingual language processing, but we are only beginning to understand the intricate cognitive and neural mechanisms that underlie this seemingly effortless skill. The emergent body of research on intra-sentential code-switching shows that switching languages within a sentence is typically associated with a measurable behavioral and neural cost, just like switching between a series of single, unrelated items. A notable difference between these two types of language switching pertains to the observed asymmetry in switching costs. Studies on intra-sentential code-switching in two directions consistently found that switching is more effortful when switching from the dominant L1 into the weaker L2 than vice versa. In contrast, single unrelated item switching is typically more effortful when switching from the weaker L2 into the dominant L1 than vice versa. These opposite asymmetries suggest that the basic mechanism underlying language switching differs in these tasks. A dominant explanation for single unrelated item switching, based on inhibitory control, is that switching into L1 is more costly because the more dominant L1 requires more inhibition when processing L2 items, and overcoming L1 inhibition when switching back to L1 is more effortful. Such item-based inhibitory control may not pertain to intra-sentential code-switching, as

bilinguals need to integrate lexical items into a coherent syntactic and semantic structure when producing or comprehending a language-switched sentence. To optimize sentence-level performance, they need to navigate the levels of L1 and L2 activation by dynamically adjusting the level of L1 activation when processing in L2, and vice versa. Clearly, more empirical research is needed to specify the functional and neural mechanisms, but it seems clear that language switching within a meaningful sentence differs fundamentally from switching between single unrelated items (and possibly from switching between full sentences, e.g., Ibáñez et al., 2010).

Furthermore, current models on the subcortical-cortical circuitry engaged in language switching are largely based on single unrelated item switching studies, and little is known about the neural substrates of intra-sentential code-switching. Given that the switching asymmetry in intra-sentential code-switching differs from single unrelated items switching, future research on the neural substrates of intra-sentential code-switching should systematically examine both switching directions.

In an attempt to bridge linguistic and (neuro)cognitive theories on switching between languages, recent studies ‘translated’ linguistic theories on code-switching into experimentally testable hypotheses using psycholinguistic techniques; these studies include tests of grammatical constraints on code-switching (Kootstra et al., 2010; Hatzidaki, Branigan, & Pickering, 2011; Guzzardo Tamargo & Dussias, 2013), including Poplack’s (1980) equivalence constraint hypothesis. In this chapter, we reviewed experimental studies that tested the psychological validity of the triggering hypothesis, originally developed on the basis of linguistic corpus research.

Quantitative analyses of off-line data drawn from linguistic corpora show that lexical triggers co-occur with code-switches in a wide variety of bilinguals, but the available experimental studies that tested the triggering hypothesis in systematically controlled

environments show that triggering facilitates intra-sentential code-switches only in specific circumstances. For example, lexical triggering appears to facilitate code-switching in discourse situations with two speakers who code-switch frequently (mimicking the typical contextual situation in which linguistic corpora of code-switches are collected), and in habitual code-switchers. In addition, cognates, false friends, and socio-contextual cues that are nouns or pronouns can trigger a switch to the other language, but verb cognates do not appear to serve this function. Clearly, more research is needed to further specify the linguistic and contextual specifics of the triggering mechanism in code-switching. Such future research, like the experimental studies testing the triggering hypothesis discussed in this chapter, will contribute to a further strengthening of the link between linguistic, psycholinguistic and neurocognitive approaches to the study of intra-sentential code-switching.

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Footnote

1) On the basis of the currently available evidence we cannot rule out the alternative explanation that the larger switching costs into L2 in intra-sentential code-switching only occurs in comprehension (i.e., reading), but not in production. Even though a similar asymmetry was found in intra-sentential code-switching when bilinguals were asked to perform a shadowing task that also includes a production component (Bultena, Dijkstra, & Van Hell, in revision; this study will be discussed later), in both reading and shadowing the linguistic input is externally induced and not controlled by the participant, so non-target language inhibition may be of less importance than is possibly the case in the production of code-switched sentences. Future research comparing the comprehension and production of code-switched sentences may shed more light on this issue.