

Electrophysiological and experimental-behavioral approaches to the study of intra-sentential code-switching

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A hallmark of bilingual language processing is intra-sentential code-switching. An emergent body of research seeks to understand the intricate neural and cognitive mechanisms that underlie this seemingly effortless skill. In this paper, we discuss electrophysiological and experimental-behavioral research approaches that have been used to study intra-sentential code-switching, and illustrate the use of these techniques by discussing a select number of empirical studies. More specifically, we discuss electrophysiological approaches that are used to study the comprehension of visually and auditorily presented code-switched sentences, including the Event-Related brain Potentials (ERPs) method, time-frequency analysis, and approaches to study inter-individual variation in electrophysiological response profiles. This is followed by a discussion of experimental-behavioral techniques to study the comprehension and production of code-switched sentences, including self-paced reading, shadowing, and confederate scripting.

Keywords: code-switching, event-related brain potentials, self-paced reading, shadowing, confederate scripting, electrophysiology

1. Introduction

Using languages in a flexible way is a common experience for many bilingual speakers. Depending on the communicative context, bilinguals sometimes restrict their language use to one language without any apparent interference from the other language, whereas in other contexts they use their languages interchangeably, often within a single utterance. This highly efficient and flexible system of

language selection, interaction, and control is an impressive cognitive achievement. Not surprisingly, bilingual language switching has proven to be a good test bed to examine the cognitive and neural mechanisms of language selection and cross-language interaction in comprehension and production, and the cognitive control mechanisms involved in this process.

Cognitive and neurocognitive studies on language switching have mainly focused on the processing of a series of single and unrelated items, such as series of isolated digits, pictures, or words. This paradigm is largely based on the task-switching paradigm that has been used for decades in cognitive psychology (for reviews, see Kiesel et al., 2010; Vandierendonck, Liefoghe, & Verbruggen, 2010). The outcomes of language switching studies indicate that switching between languages incurs a measureable processing cost that is typically explained in terms of inhibition of the non-target language and response competition, and has implications for language control (for reviews, see Bobb & Wodniecka, 2013; Declerck & Philipp, 2015). Arguably, switching between a series of single, unrelated items is different from the language switching bilinguals engage in during natural discourse, in which bilinguals produce or comprehend language switches in a meaningful utterance, such as a sentence. An increasing number of studies seek to examine the cognitive and neural mechanisms of language switching within meaningful sentences, i.e., intra-sentential code-switching (for a recent review, see Van Hell, Litcofsky, & Ting, 2015).

In this paper, we will discuss neurocognitive and experimental-behavioral research approaches and techniques that have been used to study intra-sentential code-switching, and illustrate the use of these techniques by discussing a select number of empirical studies. More specifically, we will discuss electrophysiological approaches, in particular electroencephalography (EEG), including the event-related potentials (ERPs) method and time-frequency analysis (TFR), measured during the comprehension of visually and auditorily presented sentences, followed by a discussion of experimental-behavioral techniques, including self-paced reading, shadowing, and confederate scripting. We will also outline the benefits and unique contributions of these techniques to the study of code-switching.¹ The studies we discuss that use one of these techniques typically focus on externally-induced language switches, i.e., language switches where bilinguals switch languages prompted by an external cue or respond to an externally generated switch to examine switching responses under experimentally-controlled circumstances (an exception is the confederate scripting technique discussed at the end of this

1. For a more detailed discussion on the value of these techniques for the study of first and second language processing more generally we refer to recently published edited volumes, for example, Blom and Unsworth (2010), Mackay and Gass (2011), and Jegerski and Van Patten (2014).

paper; for more detailed discussions on externally-induced switches versus internally-generated switches, see Gollan & Ferreira, 2009, and Gullberg, Indefrey, & Muysken, 2009).

2. Electrophysiological approaches to intra-sentential code-switching

A neurocognitive approach that has been used to study the comprehension of code-switched sentences is electroencephalography (EEG). Though a large portion of psycholinguistic research on intra-sentential code-switches focuses on constraints on production, EEG measures (both ERPs and TFRs) are not well suited to understanding sentential productions due to motor artifact caused by speaking. However, since code-switching is largely a conversational phenomenon, all intra-sentential code-switches must also be comprehended. EEG is an excellent measure of the covert processes engaged during the comprehension of ongoing speech. Moreover, while behavioral measures necessarily reflect the cumulative sum of all of the processing in response to a stimulus, EEG dynamically measures the millisecond-by-millisecond neural response to the stimulus. Thus, EEG can reveal the different processing mechanisms engaged during the comprehension of intra-sentential code-switches as the code-switch is encountered.

Below we will first discuss the basics of the event-related potentials (ERP) technique in language research and then describe how this technique can and has been used to study brain activation patterns associated with visually and auditorily presented code-switched sentences. We will complete this section with a discussion of more advanced analyses of EEG data that can further our insights into the neural correlates of intra-sentential code-switching.

2.1 Basic principles and application of EEG/ERPs in language research

Electroencephalography (EEG) is an electrophysiological monitoring method to record electrical activity in the brain over time. Variations in electrical activity produced by large populations of brain cells are measured by electrodes placed in key positions on the scalp. Event-related potentials (ERPs) are derived from the large amplitude EEG through a filtering and averaging process, and reflect regularities in electrical brain activity that are time-locked to an external event (for excellent introductions to ERP recordings and analyses, see, e.g., Fabiani, Gratton, & Coles, 2000; Handy, 2005; Luck, 2014; for review articles on the use of neurocognitive techniques, including ERPs, in second language acquisition research, see, for example, Sabourin, 2009, and Van Hell & Tokowicz, 2012; for a more critical discussion on the value of these methods for the field of multilingualism, see De

Bot, 2008). More specifically, small voltage changes in the EEG that are associated with, for example, reading a word on the computer screen, are time-locked to the onset of the presentation of that word, and these voltage changes make up the ERP signal. ERPs thus provide a millisecond-by-millisecond record of the brain's electrical activity during mental processing as it unfolds over time.

A typical ERP signal consists of a series of positive and negative peaks related to stimulus processing, and are termed ERP components. Exogenous components occur early in the ERP signal (< 100 ms post-stimulus onset) and are evoked by the stimulus' physical properties (e.g., its color or brightness). 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. A component either has a positive polarity (positive-going wave, labeled by P) or a negative polarity (negative-going wave, labeled by N). Latency measures reflect the time course of the ERP signal, and include onset latency (the time at which a component begins), peak latency (when a component reaches its peak amplitude), and duration (the length of the component). ERP components are often labeled according to their polarity and the latency at which their amplitude reaches its maximum (e.g., N400, as will be explained below). The relative peak amplitude of a component is assumed to reflect the degree of engagement of the associated cognitive processes. ERP components further have a characteristic topographical scalp distribution; two components similar in polarity and latency (such as the N400 and Left Anterior Negativity, LAN) that differ in terms of scalp distribution are assumed to reflect different processes. Finally, ERP components are functionally described in terms of the cognitive processes a component is assumed to reflect and the experimental manipulation to which a component is sensitive (e.g., the N400 indexes meaning integration).

The main ERP components reported in studies on intra-sentential code-switching are the N400, LAN, and the Late Positive Component (LPC; also referred to as P600). The N400 is a large amplitude negative-going wave in the 300–500 ms range that typically reaches its maximum around 400 ms post-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 & Hillyard, 1980); its amplitude decreases as the strength of the semantic relation between a word and the sentence in which it is embedded increases (e.g., Kutas & Federmeier, 2000). In the context of intra-sentential code-switching, an N400 modulation in code-switched versus non-switched sentences

implies that switching incurs a cost in the lexical-semantic integration of the switched word into the sentence.

The LAN is an anterior negativity that is often left-lateralized that occurs in the same time window as the N400 (in the 300–500 ms range), but has a different topographic scalp distribution. LAN effects have been found in morphosyntactic processing (e.g., Friederici, 2002), but also in the processing of code-switched sentences (e.g., Moreno, Federmeier, & Kutas, 2002). This switch-related LAN was interpreted to reflect increased working memory load arising from integrating morphological cues of the code-switched word (in Moreno et al.'s study: L2 Spanish) into the larger sentence context (in Moreno et al.'s study: L1 English).

The LPC (or P600) is a positive-going wave that appears around 500–600 ms post-stimulus presentation and extends for several hundred milliseconds (e.g., Hagoort, Brown, & Groothusen, 1993; Osterhout & Holcomb, 1992). It has a broad posterior scalp distribution and is maximal over centro-parietal regions. The LPC is believed to index sentence-level restructuring or re-analysis (e.g., Friederici, 1995; Kaan, Harris, Gibson, & Holcomb, 2000; Tanner, Grey, & Van Hell, 2017). In this interpretation, the LPC reflects sentence-level wrap-up or meaning revision processes that, in the case of intra-sentential code-switching, could reflect the sentence-level restructuring of two languages into a coherent utterance. The LPC is also associated with the processing of unexpected or improbable task-relevant events (e.g., Coulson, King, & Kutas, 1998; McCallum, Farmer, & Pocock, 1984), and with a reconfiguration of stimulus-response mapping (e.g., Moreno, Rodriguez-Fornells, & Laine, 2008). According to this interpretation of the LPC, a switch-related LPC reflects that bilinguals perceive a language switch as an unexpected event, and a change in form rather than meaning (Moreno et al., 2002).

What is the value of using ERPs to study intra-sentential code-switching? Behavioral techniques (to be discussed later in this paper) measure the end state of code-switching, for example, the moment a code-switched word has been read or produced. In contrast, ERPs provide an online, millisecond-by-millisecond record of the brain's voltage changes during language processing, and provide valuable information on the timing and degree of neural activation as language processing unfolds over time. ERPs provide valuable insight into the temporal dynamics of sub-processes associated with code-switching, processes that drive and determine the ultimate comprehension of code-switched sentences, but that occur before this behavioral response has been realized. For example, ERPs have been used to gain further insight into the nature of cognitive costs often associated with switching between languages, as will be discussed in the next section.

2.2 ERPs and the comprehension of intra-sentential code-switches: Visual presentation

So far, a handful of studies have used the ERP methodology to examine the processing of intra-sentential code-switches (Litcofsky & Van Hell, 2017; Moreno et al., 2002; Ng, Gonzalez, & Wicha, 2014; Proverbio, Leoni, & Zani, 2004; Van der Meij, Cuetos, Carreiras, & Barber, 2011). Most studies have focused on the comprehension of sentences with one word inserted from the other language. For example, Moreno et al. (2002) asked whether code-switches are processed similarly to within-language lexical switches in sentences. English-Spanish bilinguals read sentences in L1 English (e.g., *Each night the campers built a ..*) that ended either in a code-switch into L2 (here: *fuego* [fire]), a lexically related (and semantically less expected) English word (*blaze*; lexical switch), or a non-switched word (*fire*). While lexical switches resulted in the expected N400 effect, code-switches resulted in a LAN and an LPC. Given the different ERP responses for code-switched words and lexical switches, Moreno et al. concluded that a code-switched word in a sentence may not be more difficult to process at the semantic level than a non-switched word (as evidenced by the absence of a canonical N400 effect). Rather, bilinguals may treat an intra-sentential code-switched word more as an unexpected event at the non-linguistic level, which supports the hypothesis that switching-costs arise from outside the bilingual's lexico-semantic system. In addition, multiple regression analyses to explore individual differences among the bilinguals showed that higher scores on a Spanish vocabulary test predicted LPC responses that peaked earlier and were smaller in magnitude. Moreno et al. took this finding to suggest that the more proficient L2 Spanish speakers noticed the code-switched word earlier (earlier peak response), and found the code-switched word less unexpected and easier to process (reduced LPC amplitude).

The role of L2 proficiency was examined in more detail by Van der Meij et al. (2011) who asked higher- and lower-proficiency Spanish-English bilinguals to read sentences in L2 English that contained a sentence-medial adjective either in L1 Spanish (switch) or in L2 English (non-switch). In both the low and high proficiency groups, language-switches elicited a left-occipital N250 (indexing the initial detection of the shift driven by language-specific orthography), followed by an N400 (indexing costs associated with lexico-semantic integration) and an LPC (indexing costs associated with sentence-level updating or reanalysis processes). In the high proficiency bilinguals, the N400 effect extended to the left anterior electrodes (suggestive of a LAN, as was also found in Moreno et al., 2002). Thus, both low and high proficiency bilinguals showed processing costs related to lexico-semantic processing and sentence-level integration of the code-switched words.

Moreno et al. (2002) and Van der Meij et al. (2011) examined code-switched words embedded in individual sentences. Ng et al. (2014) conducted a study in which ERP responses were measured as Spanish-English bilinguals read short stories in English that contained eight Spanish code-switched words belonging to different classes (nouns and verbs). These code-switched words were compared with non-switched English control words in other English stories. It was found that code-switches elicited larger LAN and LPC amplitudes in comparison to non-switched words. Moreover, the N400 amplitude was larger for nouns than verbs, and an early LPC effect was observed only for switched nouns but not for switched verbs. Taken together, these results indicated that nouns incur a higher processing cost than verbs, and code-switched nouns may be harder to integrate in a sentence than code-switched verbs.

The studies of Moreno et al. (2002), Van der Meij et al. (2011) and Ng et al. (2014) suggest that intra-sentential code-switches incur processing costs (in terms of increased peak amplitudes of ERP components for code-switched words relative to non-switched words), but they examined code-switching in only one language switching direction ($L1 \rightarrow L2$ in Moreno et al.; $L2 \rightarrow L1$ in Ng et al. and in Van der Meij et al.). In contrast, Proverbio et al. (2004) asked if the direction of the switch would modulate the processing of code-switched sentences. Professional simultaneous interpreters read sentences in L1 or L2 whose sentence-final word was either a non-switch, a code-switch, or a semantically incongruous word. Code-switches resulted in an increased N400 that was larger when switching into L2 than into L1. Thus, the processing of code-switches was asymmetric, where switching into L2 incurred greater processing costs than switching into L1. RTs followed the same pattern of asymmetric switch cost. These results indicate that it is more difficult to switch into L2 than into L1 when code-switched words are embedded in a meaningful sentence (note that this asymmetry is opposite to the asymmetrical switching costs observed in studies on single, unrelated item switching, see, e.g., Bobb & Wodniecka, 2013). However, several methodological choices in this study may restrict the generalizability of the results. First, as in Moreno et al. (2002), Proverbio et al. did not control whether the code-switched words were cognates or not, which is a potential confound as research on bilingual language processing has consistently found that cognates are processed differently from non-cognates (for a review, see Van Hell & Tanner, 2012). Also, the code-switched words were always in the sentence-final position, which potentially contaminated the processing of the code-switched word with sentence wrap-up effects (e.g., Hagoort, 2003; Rayner, Kambe, & Duffy, 2000). Moreover, analyses of the code-switches were collapsed across semantically congruous and incongruous code-switched words, some of which were also an incongruous part of speech, and these semantic and syntactic incongruities may have driven (and confounded) the N400 effect

observed for code-switches. Finally, the specific and somewhat uncommon (in light of methodological improvements of the ERP technique since the publication of Proverbio et al.'s paper in 2004) presentation of the sentences may have affected processing. Specifically, the entire sentence (except the final word) was presented at once for 1.8 seconds, followed by the final word (which could be a code-switch), which may have brought extra attention to the code-switch, in addition to encouraging the use of strategic behavior as opposed to natural reading. Note also that though the authors did not examine the LPC time window, an LPC would not be expected for this study since the conditions were blocked by type such that code-switches were entirely predictable.

In a recent study, Litcofsky and Van Hell (2017) also examined the influence of switching direction on the processing of intra-sentential code-switches, testing Spanish-English bilinguals. Rather than single-word insertions, they used multi-word switches where the sentence began in either Spanish or English, switched mid-sentence, and remained in the switched language for the rest of the sentence (e.g., *'Every year, the shopkeeper makes his own juguetes para los niños pequeños'* [toys for the children]; in the actual experiment, the phrase between brackets is not presented). This type of intra-sentential code-switching is more reflective of the way in which these bilinguals typically code-switch in their daily lives (Poplack, 1980). ERP results showed that code-switched sentences only elicited a processing cost for switches into the weaker language, and that this effect manifested as an LPC. This suggests that only switches from the dominant into the weaker language require additional sentence-level restructuring mechanisms to activate and integrate the weaker language.

To conclude, the handful of studies using ERPs to study the comprehension of visually presented intra-sentential code-switches are far from being conclusive, but these first studies do yield important information about the temporal unfolding of neural events associated with different subprocesses of code-switching and the locus of code-switching costs (for a more detailed discussion, see Van Hell et al., 2015). More specifically, a switch-related N400 is typically interpreted to reflect lexical-semantic integration of the switched word into the sentence. A LAN effect has been taken to reflect an increase in working memory load arising from integrating morphological cues of the code-switched word in the sentence. A switch-related LPC effect has been taken to reflect that bilinguals process a language switch as an unexpected event in early studies (Moreno et al., 2002), but later studies consider the LPC effect to index switching costs associated with sentence level restructuring and reanalysis (Litcofsky & Van Hell, 2017; Ng et al., 2014; Van der Meij et al., 2011). As such, the switch-related N400 and LAN appear to reflect local integration (integration of lexical-semantics and morphological cues,

respectively), whereas the LPC reflects more global, sentence-level restructuring and reanalysis to integrate the two languages into a coherent utterance.

It is also clear that these studies vary widely in terms of the linguistic materials that have been used (e.g., single code-switched word embedded in sentence vs. full switch to other language; target code-switched words were nouns, verbs, or adjectives; switch from L1 to L2 or vice versa) as well as the methodology and experimental design (e.g., target word sentence-final vs. sentence-medial; blocked vs. mixed presentation; (lack of) control for potentially confounding variables such as cognate status; more commonly used word-by-word (RSVP) presentation of sentences vs. presentation of the full sentence prior to target word). With continued refinements of the ERP technique, we will be able to understand even more about the neural and cognitive mechanisms underlying intra-sentential code-switching.

2.3 ERPs and the comprehension of intra-sentential code-switches: Auditory presentation

One technique that has been largely unexplored with respect to intra-sentential code-switching, but that will potentially lead to important insights, is the recording of ERPs when bilinguals *listen* to code-switched sentences. Auditory presentation of sentences in EEG/ERP studies provides the opportunity to manipulate and study the effects that speaker characteristics, such as gender, age, and social status, have on sentence processing (Grey & Van Hell, 2017; Hanulíková, Van Alphen, Van Goch & Weber, 2012; Van Berkum, Van den Brink, Tesink, Kos & Hagoort, 2008). The inclusion of these important language cues will lead to a more naturalistic paradigm, given that code-switching tends to be more prominent in spoken conversation. Moreover, research using the shadowing technique (to be discussed below) has shown that listeners use auditory cues when comprehending code-switched sentences (e.g., Li, 1996). Importantly, auditory presentation of code-switched sentences enables to study the role of a key feature of bilingual speech production: accented speech. Currently, co-author Carla Fernandez studies the impact of foreign-accented speech on listening to code-switched sentences using auditory ERPs, which, to the best of our knowledge, is the first ERP study to explore the potential modulating effects of accented speech on intra-sentential code-switching. Her preliminary findings indicate that the effects of accented speech on switching costs appear to be dependent on switching direction and the bilinguals' language dominance, and that listening to accented code-switched sentences entails different cognitive mechanisms than listening to non-accented code-switched sentences (Fernandez & Van Hell, 2016).

Creating an auditory ERP study is more complicated than implementing a visual ERP study, which is mainly related to the inherent complexity of the auditory

signal and time-locking the EEG recording to the onset of the critical words. Several steps need to be taken to prepare materials. The first involves recording the speech, which ideally should be performed in a sound-attenuated booth to avoid white noise (common sampling rate is 44100 Hz). When possible, it is ideal to splice the recording such that the switch or word of interest is identical in all conditions. This also helps to deal with co-articulation effects. Special consideration needs to be taken in this particular step to ensure that materials remain representative of natural speech. Upon completion of the splicing procedure, the target words must be annotated to obtain the precise time of occurrence during in the sentence. By doing this, time-locking of the target words for ERP analysis is possible through the addition of triggers at the time of occurrence of each target word in the sentence.

2.4 Advanced EEG analyses and their promise for studying intra-sentential code-switching

Quite recently, several advanced analytical procedures have been introduced in the EEG literature on language processing. In this section, we will discuss two of these techniques, and explore their value for the study of intra-sentential code-switches.

2.4.1 *Oscillatory neuronal dynamics*

Analyses of neural oscillations via time-frequency representations (TFRs) provide an alternative method of examining neural activity via EEG during code-switching. Like ERPs, TFRs are a direct neuronal measure of the immediate and ongoing response to a presented stimulus. These TFRs reflect the ongoing oscillatory dynamics of the EEG signal, which reflect the (de-)synchrony of functional neural networks (Bastiaansen & Hagoort, 2006). In these analyses, power, or activity, in different frequency bands (delta: 0.5–2 Hz; theta: 4–7 Hz; alpha: 9–11 Hz; beta: 15–30 Hz; gamma: 30–60 Hz; Luck, 2014) in response to stimuli is of interest. A stimulus that requires the active engagement of the functional network results in an event-related synchronization (ERS) or increase in power in a given frequency band. In contrast, a stimulus that triggers disruption of the functional network results in an event-related de-synchronization (ERD) or decrease in power in a given frequency band. Different from ERP analyses, which only include EEG activity that is phase-locked to the stimulus (in addition to time-locked; all non-phase-locked activity are canceled out by averaging; Luck, 2014), time-frequency analyses reflect both phase-locked and non-phase-locked EEG activity, thus providing a more complete picture of the brain's response to the stimulus than ERPs.

While this technique has been used in other domains (for a review, see Pfurtscheller & Lopes da Silva, 1999), it has been less commonly applied to language

research. The growing literature of TFR studies of language processing suggests that lexico-semantic processing elicits synchronization in the theta and gamma bands (e.g., Bakker, Takashima, Van Hell, Janzen, & McQueen, 2015; Bastiaansen & Hagoort, 2006; 2015), while sentence-level processing, including syntactic unification, elicits (de)synchronization in the lower beta band (Bastiaansen & Hagoort, 2015; Weiss & Mueller, 2012).

While, to our knowledge, only one study (Litcofsky & Van Hell, 2017, see below) has examined intra-sentential code-switching using time frequency analysis, a recent study has examined oscillatory activity related to single-item language switching (Liu, Liang, Zhang, Lu, & Chen, 2017). Liu et al. were interested in the role of inhibitory control and proficiency in asymmetrical language switching, where it is more difficult to switch into the more dominant L1 than into the weaker L2 due to the need to suppress the L1 while processing in L2 (Meuter & Allport, 1999). Low proficiency Chinese-English bilinguals, of low or high inhibitory control abilities, completed a picture naming language switching task between either their L1 (Chinese) and L2 (English) or between L1 and a new language (Lnew, Korean), to which they had never been exposed. TFR results revealed increases in theta for switches into the weaker language (L2 and Lnew) as compared to switches into the L1 for the high- but not low-inhibitory control bilinguals. Liu et al. relate this theta activity to suppressing the non-target language during switching into the weaker language. However, the isolated-item switching paradigm of Liu et al. (2017) does not reflect more natural intra-sentential code-switching in which semantic and syntactic information from both languages are combined to create meaningful utterances. Yet, these findings and those from other previous TFR studies (e.g., Bakker et al., 2015, Bastiaansen & Hagoort, 2006; 2015) can provide the foundational interpretations of TFR effects, from which we can then interpret the results of intra-sentential code-switching studies.

Recently, Litcofsky and Van Hell (2017) examined the comprehension of intra-sentential code-switches in highly proficient Spanish-English bilingual speakers while EEG was recorded. As discussed above, ERP results revealed a late positivity effect to switches into the weaker language, but not into the dominant language. These results suggest that sentence-level restructuring mechanisms are recruited for switches into the weaker language. Time frequency analyses of these data revealed that switches into the weaker language showed a decrease in the lower beta (15–18 Hz) frequency band, while switches into the dominant language were associated with a power increase in the theta frequency band. These time-frequency results suggest that switches into the weaker language disrupt ongoing sentence-level restructuring processes as compared to non-switches, while switches from the weaker into the dominant language engage lexico-semantic processing to a greater degree than non-switches, possibly due to releasing inhibition of the dominant

language upon encountering the switch and re-accessing the lexico-semantics of the code-switched word (in line with the N400 ERP effects reported in this switching direction by Van der Meij et al., 2011). This first TFR study of intra-sentential code-switching suggests that using TFR and ERP analyses can provide converging, but different windows into the neural response to code-switching.

2.4.2 *Inter-individual variation in electrophysiological response profiles*

Most ERP papers show the grand average ERP waveforms across participants, and not each participant's individual waveform. The amplitudes and latencies of ERP components of these individual waveforms vary substantially across individuals, and this inter-individual variability is lost when calculating the grand average ERP waveform. To gain more insight into how individual differences in cognitive and language functions affect the magnitude of the ERP component in the grand average waveform, correlational analyses and multiple regressions analyses can be conducted that relate the magnitude or the peak latency of an ERP component (e.g., the LPC) with the score on a cognitive or language test (e.g., Boston Naming task). As discussed earlier, Moreno et al. (2002) used this analysis and observed that higher scores on the Spanish variant of the Boston Naming task (reflecting language proficiency) predicted LPC responses that peaked earlier and were smaller in mean amplitude.

An alternative method to capture individual profiles of intra-sentential code-switching originates from the L1 and L2 sentence processing literature. Several recent studies have shown that biphasic negative-positive grand mean ERP waveforms (e.g., an N400 or LAN followed by a P600) can be a result of averaging across individuals who show different ERP response profiles (e.g., Meulman, Stowe, Sprenger, Bresser, & Schmid, 2014; Tanner, Inoue, & Osterhout, 2014). For example, in their study of morphosyntactic processing in novice and proficient L2 speakers, Tanner et al. (2014) observed a typical N400-P600 grand average waveform, but subsequent computations of the response-dominance index (RDI) showed that violations of subject-verb number agreement elicited N400 effects in some individuals and P600 effects in others. Similar patterns have been found in monolingual native English speakers processing violations of core morphosyntactic constraints in English (Tanner & Van Hell, 2014). Some intra-sentential code-switching studies also obtained negative-positive grand mean ERP waveforms, mostly an N400/LAN followed by a P600 (Moreno et al., 2002; Van der Meij et al., 2011), and calculations of the RDI may reveal individual variability in neural response profiles to intra-sentential code-switching. In short, the RDI is computed as follows (for more detailed information, see Tanner et al., 2014; see formula below, derived from Tanner et al., 2014 and Tanner & Van Hell, 2014). For each individual, mean activity is computed over a centro-parietal ROI where N400 and

LPC effects are typically largest. Within this ROI, each individual's N400 effect magnitude and LPC effect magnitude are calculated. Each individual's response dominance can then be quantified and plotted by fitting the individual's least squares distance from the equal effect sizes lines using perpendicular offsets. RDI values near zero reflect relatively equal-sized N400 and LPC effects, whereas more negative or positive values reflect relative dominance of a negativity or positivity across both time windows, respectively.

$$RDI = \frac{(LPC_{switched} - LPC_{non-switched}) - (N400_{non-switched} - N400_{switched})}{\sqrt{2}}$$

The application of this response-dominance index in intra-sentential code-switching may identify bilinguals whose switching costs are more driven by lexical-semantic integration (N400) and others whose switching costs are more driven by sentence-level updating or reanalysis processes (LPC).

3. Experimental-behavioral approaches to the study of intra-sentential code-switching

In the second part of this paper, we will discuss and illustrate selected behavioral techniques that have been used in laboratory-based studies to examine intra-sentential code-switching: self-paced reading, shadowing, and confederate scripting; other behavioral techniques to study codeswitching include acceptability judgments (e.g., Badiola, Delgado, Sande, & Stefanich, 2017; Ebert & Koronkiewicz, 2017), two-alternative forced choice task (e.g., Stadhagen-Gonzalez, Lopez, Parafita Couto, & Párraga, 2017), eye-tracking techniques (e.g., Valdés Kroff, Guzzardo Tamargo, & Dussias, 2017), and the structural priming technique (Kootstra, Van Hell, & Dijkstra, 2012; for a review of behavioral techniques, see Gullberg, Indefrey & Muysken (2009). The self-paced reading technique is used to examine the comprehension of code-switched sentences, whereas the shadowing and confederate scripting techniques are mostly used to study the production of code-switched utterances.

3.1 Experimental-behavioral approaches: Self-paced reading

Self-paced reading is a paradigm that has been used in psycholinguistics to examine online the processes underlying language comprehension since the 1970s (Aaronson & Scarborough, 1976; Mitchell & Green, 1978). In a self-paced reading task, participants read through a sentence one word (or segment) at a time. The

first word of the sentence is presented visually on the computer screen and participants read at their own speed and indicate by button press when they are ready for the next word, unlike in rapid serial visual presentation tasks where the duration of each part of the sentence is pre-programmed. Participants continue in this fashion until they reach the end of the sentence, which is typically denoted with proper punctuation (e.g., a period or question mark). By having the participant press a button when they are ready for the next item, researchers are able to collect reading time data for each individual word (or segment). These reading times are then taken to reflect the amount of time necessary for a word to be processed where longer reading times reflect difficulties in processing and shorter reading times reflect ease in processing (Jegerski, 2014).

Traditionally, a self-paced reading task utilizes one of three presentations: cumulative, linear non-cumulative, or center non-cumulative (Marinis, 2010). The cumulative and linear non-cumulative presentations resemble the moving window paradigm in that the whole sentence is first represented in dashes with the number of dashes corresponding to the total number of letters and spaces in that sentence. In particular, in cumulative presentation, once a participant presses the button, a new word appears on the screen next to the previous word and the remainder of the sentence appears as dashes. In this presentation, participants thus have the option to go back and re-read the sentence. In the linear non-cumulative presentation, once a participant presses the button, a new word appears on the screen next to the previous word, but the previous word is replaced by dashes. The remainder of the sentence also appears as dashes. In this presentation, participants have a sense of how far along they are within a given sentence, but are unable to re-read the sentence. In the center non-cumulative presentation, once a participant presses the button, a new word appears on the screen in the same position as where the previous word appeared (e.g., the center of the screen). In this presentation, participants are unable to re-read the sentence and they do not receive any information regarding the length of the sentence or how far along they are within a sentence. These three presentations have advantages and disadvantages. For example, linear non-cumulative presentation more accurately represents natural online language processing by preventing the participant from going backward and re-reading earlier parts of the sentence. However, this same presentation format allows a participant to form predictions about the kind of information they may encounter in the future by providing them with information about how long the sentence is and far along they are in the sentence. Researchers must weigh the advantages and disadvantages of these presentation formats carefully when designing their study.

While completing a self-paced reading task, participants are typically given an accompanying task to ensure that they engage in reading the sentences for

comprehension and are not merely pressing the button to advance through the sentences as quickly as possible. Most often, participants are asked either to complete an acceptability judgment task or a comprehension task. This task is either performed after every sentence or after a pre-established proportion of sentences. This accompanying task therefore allows the experimenter to collect accuracy data in addition to reading time data from the individual button presses.

Although the self-paced reading paradigm was initially used to examine native language processing in real time, this paradigm has more recently been adapted to study the comprehension of code-switched sentences (e.g., Bultena, Dijkstra, & Van Hell, 2015a; Litcofsky & Van Hell, 2017; Ting & Van Hell, in preparation). Bultena et al. tested the portion of the triggering hypothesis stating that cognates can function as triggers that facilitate a switch to the other language (Clyne, 1967; 2003). More specifically, they examined whether the presence of a cognate influences the processing of an upcoming intra-sentential code-switch. They also examined whether the direction of the switch and second language proficiency influences the comprehension of code-switched sentences. Using the linear non-cumulative presentation variant of the self-paced reading task, Dutch-English bilinguals were instructed to read the code-switched sentences for meaning and had to answer comprehension questions after each sentence. The code-switch always occurred in the middle of the sentence and was either preceded by a cognate or a non-cognate. Contrary to the triggering hypothesis, analyses on the reading times revealed that cognate status did not influence code-switch processing. However, the direction of the switch did influence processing: Self-paced reading times showed a switching cost for switching from L1 Dutch into L2 English, but not vice versa. Moreover, switching costs into L2 decreased as L2 proficiency increased.

In his original writing, Clyne (1967) noted that triggers do not necessarily have to be lexical, and argued that if the context was typical for a given language, speakers would be more likely to switch into the language of this context. For example, Clyne (1967) had observed that a German native speaker working in Australia switched into English when he was asked a question about his occupation. Ting and Van Hell (in preparation) used the self-paced reading paradigm to test whether socio-contextual information can affect the processing of an upcoming intra-sentential code-switch. More specifically, do Spanish-English bilinguals process a code-switch faster when they first read a sentence containing a socio-contextual cue congruent to the language of the code-switch (e.g., '*Women in Valencia are incredibly stylish. Their *cabello* [hair] is always cut fashionably*'; in the actual experiment the word between brackets is not presented) as compared to a socio-contextual cue incongruent to the language of the code-switch (e.g., '*Women in Chicago are incredibly stylish. Their *cabello* [hair] is always cut fashionably*')? It appeared that code-switches were indeed read faster when preceded by a

congruent socio-contextual cue than by a non-congruent cue, but this effect was most pronounced in a group of highly proficient Spanish-English bilinguals tested in El Paso, who were habitual code-switchers immersed specifically in a context where both languages were used.

The self-paced reading task is a low-technology task that is relatively easy to implement. Points of critique raised against the self-paced reading task are that it requires a secondary task (e.g., a button press) to produce the dependent measure, and only provides a single measure (i.e., the total reading time of a given segment), unlike the EEG methodology or eye-tracking techniques (e.g., Frenck-Mestre, 2005). Still, self-paced reading remains a highly frequently used on-line methodology to study sentence processing and parsing in L1 and L2 (e.g., Jegerski, 2014). The studies that used the self-paced reading task to study intra-sentential code-switching indicate that this task can provide valuable insights into the comprehension of code-switched sentences (see Ibáñez, Macizo, & Bajo (2010) for an inter-sentential code-switching study that used the self-paced reading task). Furthermore, this approach can be adapted to study other factors that potentially influence the comprehension of code-switched sentences, such as syntactic structure. Findings from this paradigm can also be compared to findings from its auditory counterpart, self-paced listening, to see whether there are differences between comprehension of code-switched sentences during reading and listening.

3.2 Experimental-behavioral approaches: Shadowing

A task that has been used to study sentence production, including code-switched sentences, is the shadowing task. In the shadowing task, participants listen to recorded speech and are asked to repeat (shadow) what they hear as fast and as accurately as possible (e.g., Marslen-Wilson, 1973; Radeau & Morais, 1991). The shadowing task makes it possible to analyze the production of sentences in a controlled experimental setting. Researchers typically use two-track audio recordings: one track for the original speaker's signal of the to-be-shadowed material and one track for the recording of the participant's output utterances. The delay between the onset of the participant's reproduction of a word and this word's onset in the original recording is then calculated for each target word (shadowing latency), using speech analysis software such as PRAAT (Boersma & Weenink, 2016; www.praat.org). These shadowing latencies provide insight into the time course of processing, and variations in the delays in shadowing or the errors that participants make are taken to reflect processing difficulties.

The shadowing task has been shown to be sensitive to lexical effects, such as lexical frequency (Radeau & Morais, 1990), word length (Marslen-Wilson, 1985), and neighborhood density (Ziegler, Muneaux, & Grainger, 2003), indicating that

lexical access takes place during shadowing. In addition, Treisman (1965) observed that bilinguals showed better shadowing performance in L1 than in L2, indicating that the shadowing task is also sensitive to bilingual proficiency. The original shadowing studies documented substantial variability in shadowing performance. Close shadowers are able to repeat the stream of words at a lag of around 200 ms, which means that they start producing speech before the process of word recognition has been completed. Distant shadowers, on the other hand, first listen and accumulate information and only start repeating a word (or phrase) once they have heard the entire word (or phrase). The shadowing performance of both close and distant shadowers, however, demonstrates full lexical processing (Marslen-Wilson, 1985).

The shadowing task has also been used to study code-switching (Bultena, Van Hell, & Dijkstra, 2015b; Li, 1996; Lipski, 2013; for a code-switching study using the sentence imitation task, see, for example, Azuma & Meier, 1997). Li (1996) studied how the length of the sentence context prior to a switched word and the switched word's phonetics and phonotactic structure affect the processing of lexical switches. Chinese-English bilinguals listened to Chinese short or longer sentences that contained English code-switched words that were manipulated on phonotactic structure (CC vs. CV) and language phonetics (pronounced in English or Cantonese phonetics). Participants listened to the sentences and were instructed to only repeat the code-switched word. Lexical switches with a CC structure were harder to pronounce than switches with a CV structure, but this difference was larger when the English switch was pronounced in Cantonese phonetics than in English phonetics. Furthermore, longer shadowing times were observed for switched words preceded by a longer context than a shorter context, but length of context did not interact with phonotactic structure and language phonetics. This study indicates that phonotactic structure, language phonetics, and context all play a role in Chinese-English bilinguals' processing of code-switches sentences.

Bultena, Dijkstra, and Van Hell (2015b) used the shadowing task to examine differences in switching costs related to switching direction, as well as the predictions of the triggering theory of code-switching. Studies testing the triggering theory typically use nouns as their critical materials, but Bultena et al. examined whether verb cognates could also affect code-switching costs. They presented code-switched sentences that started in L1 Dutch and switched into L2 English, or vice versa, to Dutch-English bilinguals. The code-switch was preceded by a verb cognate (e.g., '*De ervaren schilders schetsen the flowers from a distance*' [The experienced painters sketch ...]) or a verb noncognate (e.g., '*De ervaren schilders tekenen the flowers from a distance*' [The experienced painters draw ...]). Bilinguals listened to these sentences over headphones and were instructed, as soon as they heard the beginning of the sentence, to repeat the incoming signal as quickly and as accurately as possible. Shadowing latencies showed that switching from L1

Dutch into L2 English was more costly than switching from L2 into L1 (which replicates the asymmetry observed in the self-paced reading study by Bultena et al. (2015a) and the ERP studies by Proverbio et al. (2004) and Litcofsky & Van Hell (2017)). However, switching costs were not modulated by the preceding verb cognate, indicating that shadowing a clause that contained a verb cognate trigger did not facilitate the production of the subsequent code-switch. This absence of a verb triggering effect was observed in both switching directions, and in the two syntactic structures that were tested (i.e., word order that is shared (SVO) or not shared (XVSO) across Dutch and English).

Most code-switching studies used the shadowing task in an experimental laboratory setting, but Lipski (2013) used the shadowing task in a community-based field study. He presented bilingual speakers of Palenquero (an Afro-Columbian creole language) and Spanish, living in San Basilio de Palenque (Columbia), with Spanish-only, Palenquero-only, or mixed utterances, and asked them to repeat the utterances and begin shadowing as soon as possible after the beginning of each stimulus. Lipski observed that the bilingual speakers correctly refrained from introducing Palenquero elements into Spanish-only sentences, or vice versa, so a unilingual utterance never elicited a mixed-language shadowed utterance. In their attempts to shadow mixed utterances, speakers frequently introduced language shifts: upon hearing some code-switched words, participants shadowed the sentence with a full shift to the other language; the large majority of these spontaneous language shifts were from Spanish to Palenquero.

In sum, the shadowing technique is a valuable experimental technique to study a wide range of predictions related to intra-sentential code-switching. A particular advantage of the shadowing technique is that it can be used in a laboratory, but because the technique is relatively low-tech, it can also be used in community-based field research. Moreover, because presentation is auditory, shadowing can be used to study illiterate populations as well as individuals with a low literacy level in one of their languages. This is particularly relevant for code-switching research, as many habitual code-switchers are heritage speakers (e.g., Spanish-English bilinguals from the Hispanic community) who sometimes have a low literacy level in their heritage language (e.g., Bullock & Toribio, 2009).

3.3 Experimental-behavioral approaches: Confederate scripting technique

A versatile experimental technique for the study of code-switching is the confederate-scripting technique. In the confederate-scripting technique, two participants (one of whom is a confederate, an actor who is instructed beforehand by the experimenter and whose linguistic behavior has been scripted, unbeknownst to the real participant) sit opposite each other, both with a laptop in front of them, and

perform a dialogue game in which they describe pictures to each other that are presented on their laptop. Usually, both the confederate's behavior and aspects of the pictures to be described are manipulated, and the dependent measure is typically the frequency of using a particular structure. The question of interest is to what extent the real participant's linguistic choices are influenced by this combined manipulation. Data from this technique are typically used to test theories on priming and interactive alignment between interlocutors in dialogue (see e.g., Pickering & Ferreira, 2008, for more information).

What is the unique contribution of the confederate-scripting technique to the study of code-switching? Code-switching has been found to be influenced by socio-pragmatic, linguistic, and participant-specific factors, such as relative language proficiency or whether the bilingual is a habitual code-switcher or not (see e.g., Bullock & Toribio, 2009; Gardner-Chloros, 2009; Isurin, Winford, & de Bot, 2009, for overviews). However, until recently, these factors have been studied in quite separate fields of research, all with their own research goals, theoretical paradigms, and standards on what kind of data counts as evidence. For example, sociolinguistic and linguistic research is often based on spontaneous, internally-generated language use that is collected in a non-experimental setting. This type of data collection scores high on ecological validity, but less high on internal validity. Psycholinguistic research, on the other hand, is typically based on experimental research in which the data is often based on externally induced, non-spontaneous responses. This kind of data scores high on internal validity and systematicity, but at the risk of compromising the spontaneity that is so typical of code-switching in real life. As we will illustrate, the confederate scripting technique makes it possible to systematically manipulate various forces on code-switching (i.e., socio-pragmatic, linguistic, participant-specific) in a setting that mimics important aspects of naturalistic language use.

The first published study that used the confederate-scripting technique to examine intra-sentential code-switching was conducted by Kootstra, Van Hell, and Dijkstra (2010). Kootstra et al. studied syntactic aspects of code-switching, focusing on two aspects: (1) the role of syntactic equivalence in code-switching, and (2) the potential role of interactive alignment between interlocutors in terms of syntactic choices in code-switching. The role of syntactic equivalence is most notably reflected in the idea of the equivalence constraint (Poplack, 1980), which holds that code-switching tends to take place at points in the sentence where the structure is similar between both languages. Importantly, this grammatical constraint was not yet tested experimentally or in combination with other forces on syntactic choice in language production, such as interactive alignment in dialogue (i.e., a form of structural priming). Moreover, the notion of interactive alignment had also not yet been applied to code-switching.

To test the equivalence constraint, Dutch-English bilinguals performed a task in which they read aloud a sentence fragment in a specific language and then completed this sentence fragment by describing a picture of a simple transitive event, using at least one word of the other language (e.g., they had to code-switch from reading aloud a Dutch sentence fragment to using at least one word of English in the target picture description). Importantly, the sentence fragment cued a word order that was either shared or not shared between Dutch and English. The participants were free to choose the word order and sentence location of switching in their target picture description. Consistent with the equivalence constraint, Kootstra et al. found a strong tendency to use the shared word order in the code-switched target picture descriptions, even when the sentence fragment cued a non-shared word order. Moreover, the syntactic flexibility of code-switching was higher and less dependent on switch direction when participants used the shared structure than when they used the non-shared structure.

After this ‘monologue’ task, Kootstra et al. (2010) used the same materials in a confederate-scripted dialogue situation, in which they manipulated the word order and sentence location of code-switching in the confederate’s picture descriptions. It turned out that participants had a strong tendency to copy the word order and code-switching patterns from the confederate’s previous turn. These effects were strongest in the case of shared word orders, but also occurred when the confederate produced a code-switched utterance with a non-shared word order. In these latter cases, the participants still copied parts of the confederate’s turn. This can be seen as evidence that socio-interactional influences on code-switching can interact with purely structural influences – a conclusion that would have been difficult to draw if the experiment had not used the confederate-scripting technique.

A second study that used the confederate-scripting task did not focus on syntactic aspects of code-switching, but on the tendency to code-switch. As discussed earlier, one hypothesized factor influencing the tendency to code-switch is lexical triggering by words with a similar form across languages (e.g., Broersma & de Bot, 2006). Kootstra, van Hell, and Dijkstra (in revision) tested this hypothesis in combination with the idea of interactive alignment of code-switching. The confederate and participant again described pictures to each other. This time, however, participants were completely free to use any (combination of) language(s) in their picture descriptions. To test the triggering hypothesis, the pictures contained a word with the same form across languages (i.e., cognate or homophone), or a different form. To test for interactive alignment between the confederate and the participant, the confederate code-switched in 50% of the cases and did not code-switch in the other 50% of the cases. The question of interest was whether and in what way the participant’s tendency to code-switch was influenced by the triggering manipulation in the pictures and the confederate’s code-switching. Results showed that the

real participants' picture descriptions were more often code-switched when the confederate had just code-switched in the previous turn than when the confederate had not code-switched in the previous turn. In addition, participants switched more often when the picture contained a word with a similar form across languages, but only when the confederate had just code-switched in the preceding turn. This seems to indicate that trigger words enhance the likelihood of code-switching when code-switching is already likely to occur (cf., De Bot et al., 2009), such as when a dialogue partner has just code-switched.

The confederate-scripting studies discussed above show that it is possible to study relatively unconstrained code-switching in the lab, at the same time applying experimental controls. A critical aspect of the confederate-scripting technique is that the dependent variables in the experimental tasks (i.e., the participants' responses) constitute internally generated, and voluntary, switches. For example, in the study on lexical triggering and interactive alignment (Kootstra et al., in revision), participants were completely free to code-switch or not, and code-switching was merely promoted by the confederate's code-switching. The study on shared word order in monologue and dialogue (Kootstra et al., 2010) used a procedure in which participants were indeed asked to switch, but were free to switch in any way they wanted to. Because the manner of switching and not the actual choice to code-switch was the variable of interest in these experiments, the responses in these experiments can still be regarded as internally generated. The advantage of combining internally generated responses with external cues to switch is that it provides a means to elicit relatively spontaneous code-switching in a controlled situation that will evoke a sufficiently large sample of code-switched responses in each experimental condition.

In addition, the confederate-scripting technique allows a controlled study of the impact of linguistic, psycholinguistic, and sociolinguistic factors on code-switching. For example, it is possible to manipulate the confederate's social identity, speech accent, or language proficiency, to use the confederate-scripting technique in a discourse situation with more than two people (e.g., Branigan, Pickering, McLean, & Cleland, 2007), or to vary the amount of scripting of the confederate (e.g., the director-matching task, Gullberg et al., 2009). Moreover, the confederate-scripting technique is not only suitable for the study of language production, but also for the study of language comprehension, for instance by measuring eye-movements in real-time dialogue (e.g., Kreysa & Pickering, 2011) or by recording ERPs in listeners in a dialogue context who listen to a confederate's (pre-recorded) utterances (Litcofsky & Van Hell, 2016).

4. Concluding remarks

A hallmark of bilingual language processing is code-switching, and this seemingly effortless merging of two languages into a coherent utterance highlights the flexibility of human speech, both in the production and comprehension of code-switched sentences. Intra-sentential code-switching has been studied extensively in the field of linguistics, often by analyzing linguistic corpora, and this research has yielded highly valuable insights into the structural aspects of code-switched utterances and socio-contextual factors that relate to code-switching patterns of various communities (for reviews, see, e.g., Bullock & Toribio, 2009; Isurin, Winford, & De Bot, 2009). A growing body of research within psychology examines the cognitive and neural mechanisms that underlie the comprehension and production of code-switched utterances, using laboratory-based neurocognitive and experimental-behavioral techniques that seek to maximize experimental rigor while maintaining the integrity of natural code-switched sentences common in bilingual discourse. As we learn more about the possibilities (and constraints) of the various experimental techniques as used in the study of intra-sentential code-switching, we will be able to use these techniques more flexibly and for a wider range of code-switching phenomena. For example, more recently developed techniques such as auditory ERPs can be used to study how a speaker's linguistic identity (e.g., accented speech, age, or gender) influences the comprehension of code-switched utterances. In addition, confederate scripting can be used to systematically manipulate the interlocutor's social and ethnic identity and study how this affects the online comprehension or production of code-switched sentences. Moreover, techniques that have been used successfully in the study of specific noun phrases or verb phrases (such as color-coded picture description (Fairchild & Van Hell, 2017) or eye-tracking (e.g., Guzzardo Tamargo, Valdés Kroff, & Dussias, 2016)) can also be used to study intra-sentential code-switching (see also Valdés Kroff, Guzzardo Tamargo, & Dussias, 2017). Only by integrating different experimental and naturalistic techniques and validating the code-switching patterns observed in the laboratory with those observed in everyday language in natural discourse settings, can we begin to understand the richness of code-switched speech.

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