

Code Switching and the Brain

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This chapter examines the brain bases of bilingualism, with special emphasis on language switching. Bilingual speakers differ from monolinguals in that they frequently switch between their languages, sometimes but not always intentionally. Understanding the anatomical and functional organization of the bilingual or polyglot brain may lead to better understanding of the circumstances, mechanisms, and consequences of code switching (CS). First it is necessary to examine whether the two languages of a bilingual are represented in distinct versus overlapping areas of the brain, and what brain areas are involved in orchestrating multiple languages, including switching among them. The chapter then focuses on event-related brain potential (ERP) studies of bilingualism and code switching as these brain measures afford inferences about the neurocognitive mechanisms of language processing. The chapter concludes with suggestions for some open questions that electrophysiological research could fruitfully address in the growing area of code switching.

Bilingual Brains are Different

Learning more than one language alters both the anatomical and functional organization of the brain, and apparently not just for language. Mechelli *et al.* (2004), for example, point to a significant increase in grey matter density in the left inferior parietal cortex of bilinguals relative to monolinguals – greater with earlier L2 exposure and greater L2 fluency – as a specific instance of experience-dependent brain plasticity. Coggins *et al.* (2004) explain volumetric increases in the anterior midbody of the corpus callosum (involved in primary motor and somatosensory function) in highly proficient bilinguals as an accommodation to the increased phonemic capacity requirements of bilinguals. Whatever the explanations, certain regions of the bilingual brain reliably differ from the monolingual brain in size and/or in the pattern of neural activity (e.g., Reiterer *et al.*, 2005a; Reiterer *et al.*, 2005b).

Relative to monolinguals, bilinguals are, on average, slower at naming pictures of objects, produce fewer exemplars in fluency tasks, and experience more tip-of-the-tongue moments in both their languages than do their monolingual peers (e.g., Gollan & Acenas, 2004; Gollan *et al.*, 2005; Gollan *et al.*, 2002). Whether these particular differences and others similar in kind are a consequence of the larger search space of vocabulary knowledge, of greater interference and inhibition demands, or of simply less frequent use of (and thus weaker links to) each word within a given language, are topics of intense investigation in the bilingual literature (e.g., Bijeljac-Babic *et al.*, 1997).

Perhaps, most surprisingly, there is some evidence for an advantage, beyond the obvious (communicating in another language), to being bilingual, even in the non-linguistic domain (e.g., Bialystok *et al.*, 2006). Bilingual children, for example, outperform monolingual peers in identifying the alternate image in reversible figures (Bialystok & Shapero, 2005) and in ignoring irrelevant perceptual information during card-sorting (Bialystok & Martin, 2004). This bilingual advantage in tasks involving executive or attentional control holds across the lifespan (Bialystok, 2006; Bialystok *et al.*, 2004; Bialystok *et al.*, 2006; Craik & Bialystok, 2006). Bialystok hypothesizes that bilinguals are of necessity continually exercising and thus honing their executive skills such as "selective attention to relevant aspects of a problem, inhibition of attention to

misleading information and switching between competing alternatives" (Bialystok et al., 2004; see also Hernandez *et al.*, 2001; Hernandez *et al.*, 2000). Clearly, these are the very component processes that are taxed by bilingualism in general and CS in particular – selecting words and structures from the active language, exerting inhibitory control over the currently inactive language, and switching between languages, together with maintaining the relevant word and message level representations needed, and all at the phenomenal speed with which human communication takes place.

L1-L2 Brain Overlap

The question of whether the two languages in a bilingual are represented and/or processed by the same brain region(s) or by different ones became a focus of debate following reports of bilingual aphasics displaying differential or selective patterns of language loss and/or recovery (see reviews by Fabbro, 2001a; Ojemann & Whitaker, 1978; Paradis, 1985).

Intracranial Electrical Cortical Stimulation (IECS) procedures afforded inferences about language processing in bilingual patients with epilepsy or brain tumors undergoing neurosurgery (Lucas *et al.*, 2004; Ojemann & Whitaker, 1978; Rapport *et al.*, 1983; Roux *et al.*, 2004; Roux & Tremoulet, 2002). Individual cases of bilinguals with diverse language histories and diverse language combinations were examined while brief electrical pulses were applied at different electrode sites (one at a time) as they named line-drawings, pointed to pictures of named objects, or read aloud. The stimulated brain sites most likely to disrupt L1 were more concentrated around typical language areas (e.g., posterior Sylvian fissure) than were the sites more likely to disrupt L2. Despite substantial variability within a patient and within a particular location, stimulation disrupted L1 sites more consistently than L2 sites. IECS studies generally offered little if any support for the hypothesis that language representation in bilinguals has a greater than normal contribution from the right hemisphere (see also review by Paradis, 2000a; Rapport et al., 1983), with the proviso that most stimulations occur in the left hemisphere. Like the patient data, the IECS findings also support only partial overlap in neural representations of the languages in bilinguals, with a mosaic pattern of L1-L2 representation where two adjacent cells could be language-specific.

Initial results of the scanning of intact bilingual brains with Positron Emission Tomography (PET) and functional Magnetic Resonance Imaging (fMRI), two techniques used to infer neural activity from changes in metabolic activity or blood flow, were similarly variable, with some researchers claiming identical brain areas for L1 and L2 (Klein *et al.*, 1995; Klein *et al.*, 1994) and others highlighting activation differences (Dehaene *et al.*, 1997; Perani *et al.*, 1996; Yetkin *et al.*, 1996). Likewise, while some researchers report greater brain extent (number of activated pixels) for the less fluent language (Yetkin et al., 1996) others found the opposite pattern (Perani et al., 1996). Across these studies, however, participants vary considerably in their relative language proficiencies and performed different tasks ranging from word generation to story listening. Nonetheless, there tends to be greater intersubject variability in the cortical representation of L2 than of L1 (Dehaene et al., 1997).

Given these inconsistencies, researchers began to assess the influence of individual, language, and task characteristics that could reasonably be expected to account for the variability. This research tack hints at the assumption that the brain areas

serving L1 and L2 can be identical in principle but may not be in practice because of differences in when or how each is acquired, and/or how well each is known, and/or the distance between the languages, the difficulty or level of language analysis, etc.

Some researchers, for example, argue that earlier L2 exposure leads to greater sharing of neural space with L1 (Kim *et al.*, 1997). Other investigators, however, find that age of acquisition *per se* has little effect on either the precise location or neural extent of L2 representation if L2 proficiency is high (Illes *et al.*, 1999; Perani *et al.*, 1998; Pu *et al.*, 2001). Language proficiency, by contrast, is found to have a significant, albeit differential, impact on neural extent (number of activated pixels) of comprehension and production processes (Briellmann *et al.*, 2004; Chee *et al.*, 2001; Perani *et al.*, 1996; Yetkin *et al.*, 1996). This inverse correlation between activation and production proficiency may be a specific instance of a more general finding that increasing expertise is accompanied by a decrease in cortical activation (Briellmann *et al.*, 2004).

Although the typological distance between the structures of two languages also might seem to be a reasonable factor influencing how the languages are represented, there is apparently no reliable evidence that it is. The degree of L1-L2 activation overlap is about the same for Italian and English as it is for the typologically similar languages (e.g., Catalan and Spanish) (Perani *et al.*, 1998) or two typologically diverse languages (e.g., English and Chinese) in both early and late bilinguals (Chee *et al.*, 1999a; Chee *et al.*, 1999b).

Some researchers have examined the possibility that the answer to the question of L1-L2 brain overlap varies with the specific language processes under investigation (e.g., phonological, morphological, syntactic, and semantic), which at times is modulated by proficiency in and/or age of exposure to L2. With respect to the issue of language process, greater convergence was seen for semantic and phonological tasks in L1 than in L2 (Pillai *et al.*, 2003), greater activation for negative compared to affirmative spoken sentences was seen only in L2 (Hasegawa *et al.*, 2002), and more brain areas distinguished active from passive sentences in L1 than in L2, at least in late bilinguals (Yokoyama *et al.*, 2006). With respect to proficiency and age, it has been claimed that proficiency has a major impact on neural processing for semantic judgments, and age of acquisition is more critical for grammatical processing (Wartenburger *et al.*, 2003). Furthermore, while L2 proficiency is an important determinant for semantic processing, its effects are primarily beyond the word level (Xue *et al.*, 2004). Finally, age of exposure influences linguistic tasks with isolated words, but not with more complex stimuli such as whole sentences (Frenck-Mestre *et al.*, 2005).

General considerations of L1/L2 overlap

While the initial research focus on the degree or extent of overlap of the two (plus) languages of a multilingual has been refined to include the modulatory effects of individual factors (e.g., age of exposure, proficiency, daily usage), as well as linguistic and task factors (e.g., linguistic difficulty/complexity, language level/process), there exist, nonetheless, different accounts of which factors are most important for particular processes (for reviews see Abutalebi *et al.*, 2001; Fabbro, 2001a, 2001b; Perani & Abutalebi, 2005; Vaid & Hull, 2002).

Age and mode of acquisition, for example, play key roles in Ullman's model of bilingual processing (Ullman, 2001) underscoring his view that it is how the two languages are acquired rather than differences in relative proficiencies that determine the brain areas engaged. All lexico-semantic knowledge in L1 and L2, as well as L2 grammar when learned later in life, is presumed to rely on a declarative memory system. By contrast, the grammatical knowledge of L1 is implicitly acquired, thus leading to differential L1-L2 activation in grammatical tasks. This model, however, fails to account for brain-based L1-L2 differences as a function of L2 proficiency. Alternatively, Perani and Abutalebi (2005) maintain that the brain areas involved in language learning change throughout the course of learning much as they do for non-language learning (Briellmann et al., 2004), such that the neural processing of L2 "converges" to that of L1 with increasing proficiency. They argue that the same brain mechanism supports grammatical processing in L1 and L2, with differences attributable to the different cognitive strategies adopted to compensate for lower L2 proficiency. Paradis (Paradis, 2000b, 2003) similarly argues that the apparent differential lateralization of brain function for L2 is strategic, with greater reliance on metalinguistic knowledge and pragmatics under right hemisphere control. On Indefrey's account (2006), late L2 acquisition onset, low L2 proficiency, and low exposure to L2 are all important in determining brain organization for L2, albeit with different weightings for different language processes. Specifically, word comprehension processes are influenced primarily by L2 proficiency, sentence comprehension processes primarily by L2 onset, and word production processes by all three factors.

In summary, there is no simple answer to the question of whether the neural representations of the two languages in a bilingual are or are not the same. Neuropsychological data and intraoperative electrocortical stimulation mapping data in bilinguals suggest that the brain regions serving L1 and L2 are not identical, although there may be substantial overlap. Neuroimaging data would seem to indicate that although L1 and L2 largely engage similar brain areas, there are individuals in whom there are circumstances when the activated brain areas differ. Some researchers interpret activation differences in the same general region as support for one language system, albeit with different degrees of activation, whereas for others it is evidence for the different neural representations of L1 and L2. When differences in brain regions for L1 and L2 are observed, it is more common to see greater activation during L2 processing than during L1 processing, presumably due to differences in age of exposure to L2, amount of L2 exposure, L2 proficiency, or some combination thereof. Moreover, these factors seem to make different contributions to different language tasks, presumably because different tasks tap into different linguistic and/or cognitive processes, although there is not yet a consensus as to which are the most relevant (e.g., comprehension vs. production, lexical vs. sentential, grammatical vs. semantic). At minimum, researchers of bilingualism know that it is essential to determine age of acquisition as well as L1 and L2 proficiency, and to exercise caution when generalizing from any particular language task to language more generally.

Whatever the degree of neural overlap between L1 and L2, many questions remain: How do the different languages in bilinguals stay functionally segregated, if they do? What sorts of relationships exist between the languages at each level (lexical, phonological, morphological, syntactic)? How do bilingual speakers choose the right word in the right order in the intended language? How is access to the different

languages controlled and how is interference prevented, if it is? Are both languages in a bilingual always “on” or can one be shut off when it is not in use? If so, then, is there a cost to switching to the unused language, always or only sometimes? To what extent do the answers to these questions differ as a function of bilingual characteristics, the stimuli, the language environment, language in use, and/or the task, among other factors?

These are the sorts of questions that electrophysiological researchers address by recording electrical brain activity from the scalps of bilinguals as they comprehend or produce language. For the most part, the electrical activity at the scalp reflects summed post-synaptic potentials (excitatory and inhibitory) generated primarily by pyramidal cells in the neocortex. The magnetic counterpart – the magnetoencephalographic (MEG) – reflects a subset of this activity generated by pyramidal cells that are oriented tangentially to the scalp surface. Researchers look to this electrical activity locked in time to stimulus presentation or response onset and averaged across multiple occurrences of the relevant stimulus or response class – the event related brain potential (ERP) – to track stimulus or response-related processing. By comparing two or more patterns of such voltage waveforms in time and space elicited under different experimental conditions, investigators make inferences about when (and where at the scalp) certain differences between the conditions first appear and what these differences might mean in terms of sensory-perceptual, motor, and cognitive constructs.

Electrophysiological patterns in bilingual readers and speakers

The ERP is a waveform of voltage in time, reflecting the difference in electrical potential between two recording electrodes, elicited by and synchronized in time to an event of interest, as a signal travels from a receptor to a percept, a concept, and on occasion to a memory representation or an overt response. The waveform consists of negative and positive peaks (with respect to pre-event baseline) typically labeled with their polarity and latency (N100, a relative negativity peaking at 100 ms after stimulus onset, or P200, a relative positivity peaking at 200 ms after stimulus onset, both of which are obligatory sensory components that vary with parameters of the physical stimulus and attentional manipulations). Each peak (or temporal region of a waveform) can be characterized in terms of its amplitude, latency with respect to the event, and amplitude distribution across the scalp. Each of these characteristics of the ERP for different conditions for each participant can be subjected to an analysis of variance or regression analysis in order to determine which differences between conditions are statistically reliable. Although not identical to components, peaks are often taken as overt markers of latent components that index specific neural computations implementing certain psychological processes. Many such components have been described in the cognitive ERP literature. Two relatively late so-called endogenous components in particular have played important roles in psycholinguistic studies: the N400, a negative peak around 400 ms sensitive to lexico-semantic processes and the P600, a positive peak around 600 ms sensitive to grammatical processes. By contrast to the early so-called exogenous components such as the P1, N1 and P2, these components are much less sensitive to physical stimulus features, and much more sensitive to how an individual processes the eliciting stimulus or in some cases the absence of the “expected” stimulus. Two other endogenous components used primarily in electrophysiological studies of language production are the lateralized readiness potential (LRP) and the nogo N200; the LRP is a derived measure that can be used

under the appropriate experimental conditions to indicate preferential response activation, whereas the nogo N200 can be used in a go/nogo paradigm as an index of response inhibition. In response conflict and go/nogo paradigms, both of these ERP components can be used to track the time course of the encoding of features and response activation, thereby supporting inferences about the relative ordering of information availability during language production.

It is not at all uncommon to see differential patterns of electrical brain activity in monolinguals relative to bilinguals or within bilinguals for L1 versus L2. The difficulty is determining which differences are reliable and what functions they index. To date, the majority of electrophysiological investigations in bilinguals have looked at some aspect of language comprehension, focusing on the N400 (Kutas & Hillyard, 1980b). Negativity in the N400 range (200-500 ms post-item onset) is a default response to all potentially meaningful items, not just language (words, pseudowords, sign language, gestures, line drawings, e.g., Ganis *et al.*, 1996; Kutas *et al.*, 1987; Wu & Coulson, 2005). N400 amplitude is modulated by a number of factors that influence the ease with which information is accessed from semantic memory, such as word frequency (smaller for high frequency), word repetition (smaller with repetition), and semantic context (smaller with relatedness). The N400 is used in semantic priming paradigms as an index of associative/semantic priming, although the potential in the same window is also sensitive to phonological and orthographic relationships. Within sentences, N400 amplitudes to given words are reduced by contextual constraints that seem to pre-activate aspects of upcoming items prior to their occurrence and/or ease their integration into the ongoing message-level representation upon their occurrence (e.g., Federmeier & Kutas, 1999; Wicha *et al.*, 2003; Wicha *et al.*, 2004). The effect of context is especially evident in the N400 semantic congruity effect: the difference in the ERP to a word that is a good semantic fit with a prior sentence context (congruent) and to one that is a bad semantic fit (semantically incongruent, although the N400 per se is not unique to semantic anomalies; e.g. 'He shaved off his mustache and *eyebrows*'). Over frontal sites, N400 amplitudes vary with concreteness and with word class (Brown *et al.*, 1999; Holcomb *et al.*, 1999; Kounios & Holcomb, 1994; Weber-Fox *et al.*, 2003). N400 amplitude is also affected by language proficiency even in monolinguals (King & Kutas, 1995; Weber-Fox *et al.*, 2003). It develops rapidly in young adults learning a second language, with as little as 14 hours of training sufficing to distinguish real words from nonsense words (McLaughlin *et al.*, 2004).

The N400 has been used to examine lexico-semantic information processing in one or the other, or both, of a bilingual's two languages. Bilinguals typically show an N400 relatedness effect (smaller N400s to the second of a pair of semantically related than unrelated words) in both of their languages, much like monolinguals (see Kotz & Elston-Guttler, 2004 for an exception). However, the timing and degree of access to information in semantic memory in each of a bilingual's languages seems to be modulated by both proficiency and age of acquisition. Bilinguals who are fluent in both their languages from birth tend to show equal amplitude N400 semantic priming effects in both (Kotz, 2001). Bilinguals who are imbalanced either in proficiency or age of acquisition do not: larger N400 relatedness effects are seen during the processing of the more proficient language and for the earlier learned language (Kotz & Elston-Guttler, 2004; Phillips *et al.*, 2004).

In sentence processing studies, the focus is usually on the N400 congruity effect, which is linked to semantic expectancy and/or semantic integration. In a few cases, the N400 semantic congruity effect has been found to be about the same size in bilinguals (especially in L1) as in monolinguals (Ardal *et al.*, 1990; Anja Hahne & Friederici, 2001; Proverbio *et al.*, 2002; Sanders & Neville, 2003; Weber-Fox & Neville, 2001). In other cases, however, there are some noteworthy differences in the N400 congruity effects between monolinguals and bilinguals, and between the two languages of a bilingual in overall amplitude, onset and peak latencies, and/or relative amplitude distributions across the scalp. Importantly, these differences are modulated by proficiency (Proverbio *et al.*, 2002) as well as age of acquisition (Weber-Fox & Neville, 2001), although these two factors are often difficult to dissociate (Moreno & Kutas, 2005).

Whether the N400 is taken to reflect semantic expectancy or integration, systematic variations in N400 onset and peak latency afford inferences about when semantic information becomes available for use. Some studies have reported longer latency onsets or peaks for the N400 congruity effect in bilinguals compared to monolinguals (Ardal *et al.*, 1990; Hahne & Friederici, 2001), within bilinguals for their less-dominant language compared to the more-dominant one (Ardal *et al.*, 1990; Moreno & Kutas, 2005) and for those who acquired the language later in life (though note that even for monolinguals, N400s are delayed in those who are less proficient language users Weber-Fox *et al.*, 2003; e.g., Weber-Fox & Neville, 2001). More specifically, the latency of the N400 congruity effect in L2 is positively correlated with age of exposure and inversely correlated with fluency (Moreno & Kutas, 2005). The duration of the N400 congruity effect also may be longer for bilinguals in their less proficient language relative to monolingual readers (Hahne, 2001; Hahne & Friederici, 2001). The observation of slowed N400 congruity effects in both languages of a bilingual (relative to monolinguals) suggests that simply being bilingual may have processing consequences for certain semantic analyses. This is consistent with observations of slower reaction times even in L1 for bilinguals compared to monolinguals, although the N400 congruity effect does not always distinguish between monolinguals and a bilingual's L1 (e.g., Proverbio *et al.*, 2002). Similarly, the difference in timing between L1 and L2 clearly reflects differences in speed of access to lexical-semantic information in each language.

In summary then, bilinguals have access to word-level meanings in both their L1 and L2, although the speed and perhaps extent of effective access to that information is a function of language proficiency. Higher proficiency is associated with larger semantic priming effects and sometimes larger sentence level effects, although even the most highly proficient L2 users can be distinguished from strictly monolingual language users on N400 latency, amplitude and/or distribution.

Fluent speakers of two or more languages are remarkably adept at accessing information from one language or the other selectively, although not always without cost. Nonetheless, given the apparently substantial overlap in the neural networks of a bilingual's two languages, it is noteworthy that many bilinguals do not seem to suffer much interference between their languages. Perhaps there is in fact no interference because the bilingual brain completely shuts off one language while the other is on. Alternatively, the bilingual brain may regulate the use of two languages, both of which are always on, so as to minimize interference. Or, perhaps interference is more

pervasive than obvious in overt behavior. Whether only one language of a bilingual is “on” (selective) or both languages are “on” (non-selective) at any given moment is a particularly controversial question (e.g., Dijkstra & Heuven, 2002). There are data consistent with both of these positions.

ERP researchers typically take cross-language priming/interference as evidence for activation of both languages as opposed to selective activation of just one. When a word in one language influences the ERP to the translation equivalent or to a semantically related word in the other language, it is assumed that both must be “active”, at least to some degree. Similarly, if features of one language somehow modulate processing of the other, then it is assumed that both are effectively “active” to some extent at that time. Interaction/interference can be inferred from amplitude and/or latency alterations in many different ERP responses, depending on the brain process affected.

To date, a number of ERP investigations have suggested that fluent bilinguals can at least sometimes selectively activate one language, particularly when the processing task is monolingual (Rodriguez-Fornells *et al.*, 2002). However, when the task performance requires that both languages be quickly available (Rodriguez-Fornells *et al.*, 2005) or includes word stimuli such as interlingual homographs (words that share their form but not their meaning across two languages) that are an integral part of the lexicon in both languages, then interference/interaction is more likely (de Bruijn *et al.*, 2001; Elston-Guttler *et al.*, 2005b; Kerkhofs *et al.*, 2006; Paulmann *et al.*, 2006); such interference is reflected in different ERP components indexing different cognitive processes including the N400, but is subject to modulation by context (Elston-Guttler *et al.*, 2005a). Research with translational homonyms (two words in one language which translate to the same word in another, e.g., “pine” and “jaw” both of which translate to *Keifer* in German) also offers evidence for cross-language interference even when the processing task is monolingual (de Bruijn *et al.*, 2001).

Unlike in the semantic domain where even late learners show N400 congruity effects similar to those of native speakers, bilinguals do not always show the typical monolingual ERP effects (P600 and left anterior negativity or LAN) to syntactic violations and grammatical analyses (Hahne, 2001; Hahne & Friederici, 2001; Hahne *et al.*, 2006; Mueller *et al.*, 2005; Sanders & Neville, 2003). The P600 (Holcomb *et al.*, 1999; Osterhout & Holcomb, 1992) is elicited by both local and global grammatical processes, including violations of subject-verb agreement, pronoun agreement, phrase structure violations, subacency violations, subcategorization violations, among others, but is also observed with no overt syntactic violation and even in non-linguistic contexts such as to certain musical violations (e.g., Coulson *et al.*, 1998; Patel *et al.*, 1998). The LAN is a relatively early negativity often seen in association with violations of syntactic well-formedness as well as to manipulations of syntactic working memory (e.g., Kluender & Kutas, 1993; Muentel *et al.*, 1993). For example, Mueller and colleagues (Mueller *et al.*, 2005), found that although non-native speakers of Japanese were able to learn a mini-version of the language, with 75% accuracy in grammatical sentence production and comprehension with only 4-10 hours of training, not all their ERP effects appeared native-like. In particular, whereas the bilingual and monolingual ERPs resembled each other for the P600 to word category and case violations, they were qualitatively different in response to more complex grammatical processes (e.g.,

thematic role assignment); learners were characterized by a complete absence of the negativities (eLAN and N400) observed in monolinguals.

In sum, several different factors can influence the apparent selectivity of access to one language or another during language processing in bilinguals. The effects of these factors – especially relative language proficiencies, language environment, language of local context and task demands – are all worth considering, as they are just as likely to be important when bilinguals actively use two languages, as in CS. Likewise, it is important to note that semantic and certain grammatical/syntactic processes are differentially impacted by bilingualism.

Switching: Structure and Function

The remaining sections focus on CS, first examining the neuroanatomy of CS then reviewing the handful of electrophysiological studies devoted to CS.

Subcortical-Cortical network for language switching

Case studies of bilingual patients with cerebral lesions have been a major source of theorizing about the brain areas involved in translation, language mixing (clinically defined as mixing words between two or more languages within a single utterance), and language switching (clinically defined as switching between languages in complete sentences). Although translation, language switching, and language mixing are typically tied to separate brain mechanisms, the network specifics vary across proposals (e.g., Fabbro *et al.*, 1997; Fabbro *et al.*, 2000; Obler *et al.*, 1978; Perecman, 1984; Price *et al.*, 1999). Herein, we use code switching and language switching synonymously, encompassing switching within or between single utterances, as is common in the experimental literature.

Language switching hypothetically relies on inhibition of the non-target language via the left basal ganglia (Abutalebi *et al.*, 2000; Fabbro *et al.*, 1997; Marien *et al.*, 2005), and/or attentional/executive control mechanisms involving the anterior cingulate, prefrontal and frontal cortices (Fabbro *et al.*, 2000; Hernandez *et al.*, 2001; Hernandez *et al.*, 2000), or bilateral supramarginal gyri and Broca's area (Price *et al.*, 1999). Pathological or uncontrollable language switching is presumed to reflect deficits in selection processes and has been reported for all levels of linguistic processing, including phonological and morphological blends, intonation patterns, and syntax. The most common form, however, is lexical insertion of words from one language interjected into sentences in another language (Perecman, 1984), which sometimes occurs equally in both directions (e.g., Abutalebi *et al.*, 2000; Fabbro *et al.*, 2000), but is more often asymmetric (e.g., Aglioti & Fabbro, 1993; Fabbro *et al.*, 1997).

Patient data as well as neuroimaging data from healthy adults generally implicate a cortical-subcortical network (including the thalamus, basal ganglia, and frontal cortex) in language switching (Fabbro *et al.*, 1997; Marien *et al.*, 2005). Some researchers consider the dorsolateral prefrontal cortex (DLPFC) key for controlling language switching and inhibiting the currently unused language, as damage to the DLPFC sometimes leads to uncontrollable language switching. Repetitive transcranial magnetic stimulation of the DLPFC in severely depressed bilinguals elicits the experience of thinking in and having an urge to speak in their less frequently used

language (Holtzheimer *et al.*, 2005). Similarly, neuroimaging studies show increased activation in the DLPFC during language switching (Hernandez *et al.*, 2001; Hernandez *et al.*, 2000), although not always (Crinion *et al.*, 2006; Price *et al.*, 1999). Likewise, damage to the basal ganglia and/or to their frontal projections leads to pathological and/or spontaneous code switching. The left basal ganglia and thalamus are presumably important for *inhibitory* control of an unintended language, especially the more automatized language (e.g., Aglioti *et al.*, 1996; Aglioti & Fabbro, 1993). The left caudate also has been variously linked to the *selection* of desired lexical items, control of the language in use in bilinguals, and the inhibition of the unintended language (e.g., Crinion *et al.*, 2006).

Although presumed essential for multilingual language processing, this cortical-subcortical loop does not appear to be unique to multilinguals, or even to language (e.g., Aglioti, 1997; Crosson, 1999; Paradis & Goldblum, 1989; Zatorre, 1989). It has been linked to lexical selection in monolinguals (Crosson *et al.*, 2003), as well as to lexical selection across languages in polyglots (e.g., Abutalebi *et al.*, 2000), consistent with the possibility that bilinguals have co-opted existing mechanisms for lexical selection and inhibitory control within a language for multi-lingual control. In fact, a basal ganglia-frontal cortex pathway is more generally thought to be involved in cognitive control processes in multiple domains (memory and attention), not just language (Aglioti, 1997; Alexander & Crutcher, 1990).

In sum, data from patients as well as from neuroimaging studies in healthy adults have implicated both subcortical and (prefrontal) cortical structures in voluntary and involuntary language switching. Subcortical structures, especially in the basal ganglia, are presumably involved in language selection and/or inhibition mechanisms that are not necessarily specific to bilinguals, but important for their code switching.

The bilingual psycholinguistic literature is rife with examples of the ‘cost of code switching’ as inferred from longer reading times for bilingual versus monolingual texts (Macnamar & Kushnir, 1971) or from longer lexical decision times for words that are immediately preceded by a different language than by the same one (Grainger & Beauvillain, 1988; Grainger & Oregan, 1992). So, clearly code switching can incur a cost. The question, however, is whether it always does so, or whether there are circumstances under which code switching is not costly, and perhaps even beneficial (see Li, 1996). Additionally, the predictability of a switch (as in a blocked stimulation design) has sometimes (although not always) been found to reduce (Altarriba *et al.*, 1996; Meuter & Allport, 1999) or eliminate costs (Chan *et al.*, 1983). ERPs can provide us with a direct measure of the electrical (neocortical) brain activity associated with producing and processing switches of language. The handful of ERP studies of code switching in bilinguals is reviewed next.

Brain Response to the production of language switches

Jackson *et al.* (Jackson *et al.*, 2001) recorded ERPs from native English speakers as they randomly named digits in L1 (English) or in L2 (French, German, Spanish, Mandarin or Urdu); language was cued by the ink color. Participants were slower to name digits after a language switch, to the same extent regardless of switch direction, and also were slower to name digits in L2 than L1 on non-switched trials. Language switches were associated with a larger fronto-central N320 component and a later

posterior positivity (late positive component or LPC) relative to no switch trials. The N320 was taken to index inhibition of the unwanted lexicon. Unlike the RT effect, this N320 effect was evident only for switches from L1 to L2, perhaps reflecting a greater need for resources to suppress an active L1 in order to produce an L2 word than vice versa. The enhanced LPC (385-700 ms) was hypothesized to index the reconfiguration of stimulus-response linkages necessary to regain access to the previously inhibited lexicon.

Overall, these results support models in which effective production of one language requires inhibition of the other, though the inhibition mechanism need not be language specific. Inhibition, of course, need not be all or none, and may be influenced by age of exposure to L2 and/or language dominance.

Event-related brain potential (ERP) responses to code-switches during language comprehension

Whereas naming a digit in one language may require deliberate suppression of its name in the other language, one can imagine that suppression might be less important during comprehension. To examine this issue, Jackson et al. (Jackson *et al.*, 2004) presented bilinguals with a sequence of number names that alternated predictably between languages (e.g., *two-one-cinq-sept-four-eight*) and asked them to judge whether the number was even or odd, regardless of its language. Code-switches did not elicit an enhanced N320 (considered equivalent to a nogo N200), suggesting no suppression of the alternate lexicon. These results point to an overall difference between the effects of language switching at the word level on production and comprehension, particularly when the task requires both languages to be active (see also Rodriguez-Fornells et al., 2005). They suggest that the absence of the N320 effect might mean that switching costs during comprehension may occur outside the lexico-semantic system.

Moreno et al. (2002) were interested in determining whether the bilingual brain responds to a language switch as an orthographic/physical deviation (larger late positivity, e.g., Kutas & Hillyard, 1980a), a semantic deviation (larger negativity, or N400, e.g., Kutas & Hillyard, 1980b), or as both. To that end, the ERPs were recorded in English/Spanish bilinguals reading highly constraining English sentences such as 'He put a clean sheet on the...' which could end with 1) the most expected word ending in that sentential context ('bed'); 2) a so-called lexical switch, or synonym of the expected word in English ('mattress'); or 3) a code-switch, i.e., a translation equivalent of the expected word in Spanish ('cama'). Relative to expected endings (*bed*), within language switches (*mattress*) elicited a larger N400 while code switches into Spanish (*cama*) elicited a large posterior late positive component (450-850 ms), consistent with the proposal that code switches were treated more like unexpected events at the physical level than at the lexico-semantic level. The more proficient the bilingual in L2, the earlier in latency and the smaller in amplitude was this positivity to the code-switch.

Proverbio et al. (2004) also examined the nature of ERPs to code-switches, but, within a group of professional simultaneous translators, presumably proficient in at least four different languages. These polyglots were examined in L1 (Italian) and L2 (English) as they read a sentence context followed ~1.5s later by a final word and made sense/nonsense judgments in two unmixed conditions with sentences and two mixed (but predictable code-switch) conditions. As expected, reaction times revealed

switching costs: interpreters were slower to respond to mixed than unmixed sentence conditions even though there was no uncertainty about when the code-switches would occur. Several CS ERP results were reported, including larger N400s (300-500 ms) for language mixed final words compared to unmixed sentence endings, collapsed across congruity. Also, collapsed across congruity, N400s were reportedly larger when CSing from the more-dominant to the less-dominant language than vice-versa.

Finally, although Alvarez et al. (2003) were more generally interested in characterizing the functional organization of L1 and L2 word processing in individuals early in L2 acquisition process, their design offers data relevant to CS. Their primary focus was on ERP word repetition effects, as numerous studies have documented reductions in N400 amplitude upon word repetition (e.g., Bentin & Peled, 1990; Besson *et al.*, 1992). ERPs were recorded to a series of English and Spanish words (one every 2.7s) from English L1 speakers as they pressed a button for words from a particular semantic domain in either language (approximately 10% of words). Alvarez et al. aimed to determine how much of the within language effect on N400 reduction is semantically driven. Whereas within language repetitions overlap in form and meaning, between-language repetitions of a word and its non-cognate translation equivalent share meaning but have minimal orthographic and phonological overlap. Critically, for present purposes, the main comparison of within language repetitions versus between language repetitions included CS in both directions. Even though participants could not be sure when a code switch would occur, they could predict with great certainty what the code switch would be when it did occur. As expected, immediate repetitions reduced N400 amplitudes, and these reductions were greater for within- compared to between-language repetitions, just as they are for exact repetitions versus semantic level repetitions. Moreover, although between-language ERP repetition effects were about the same size overall regardless of the direction of the switch, the time course of the repetition effect varied with switch direction, being earlier for switches into L1 than into L2. These findings are generally consistent with some asymmetry in the strength of lexical connections between L1 and L2, which Kroll and Stewart (1994) have hypothesized as a lifelong asymmetry, albeit modified by L2 fluency. If true, then with increasing L2 proficiency, there should be less of a difference in the size of the N400 repetition effect across a bilingual's two languages, as a function of switch direction.

In sum, only a handful of studies have examined the electrical brain activity accompanying language code switches in production or comprehension. Code switch-related effects have been observed on the N1, N320, N400, late positivity, and/or on a late (post N400) negativity, although never in the same study. It is difficult at present to compare results across experiments given the differences in experimental design and populations. It will be important to determine how certain factors contribute to the pattern of ERP effects observed, including: (1) predictability in timing or content of the CS; (2) frequency of the CS; (3) the direction of the CS; (4) language proficiency and/or dominance; (5) age of acquisition; (5) language process under investigation; and (6) task demands. Although no unified picture of ERP effects of CS has yet emerged, it is unlikely that there will be a single ERP marker of language switching. More likely, different switch-related ERP effects will be elicited depending on which perceptual/cognitive/motor process is affected by switches.

Conclusions

Psychological and brain research are difficult for reasons that need no enumeration here. Research with bilinguals or polyglots is much harder still. If only researchers could “raise” multi-language individuals in controlled environments, conducting parametric studies and, manipulating all the linguistic factors now known to be important for language learning and use. They can’t. They make do by choosing more homogeneous populations, collecting information about language history, and assessing the language capabilities of the multilingual participants. Nonetheless there is more variance in the data than we can handle, and the literature remains somewhat inconsistent and incoherent. This, then, may be a good time to step back and be clear about what questions to ask. Simply recording some measure (brain or otherwise) in response to a CS without a clear theoretical motivation will just add to an already confusing mix of data patterns.

Although there is still some measure of uncertainty and disagreement as to the exact functional significance of various ERP components, there is some predictability to the pattern of effects obtained in particular paradigms and a limited range of hypotheses as to what manipulations and/or processes modulate them. It is thus possible to use known components to examine hypotheses about group or language differences at the level of sensory and attentional processes, consolidation into working memory, inhibition, relative response preparation, short term auditory memory or more generally attention independent change detection, semantic/conceptual level of analysis, error or conflict processing, prosodic boundaries, among others. None of these components, however, is a marker in the sense that we can look for it in an ERP waveform and from it alone (without knowledge of the stimuli, experimental design, and task demands) infer the engagement of an underlying cognitive/neural operation. These ERP components can, however, serve as markers under the appropriate set of experimental conditions chosen with specific alternative hypotheses in mind. An important point to note in this regard is that various components should not be dismissed as useless simply because they have not routinely or not yet been employed in language studies. Given the right question, every ERP component can be fruitfully harnessed to analyze both linguistic and non-linguistic processing in monolinguals and bilinguals. One can imagine electrophysiological studies specifically aimed, for example, at assessing whether or not switching (during reading or listening) captures attention (focussing on attention-related components), or whether switching is sometimes expected but at other times considered an error (focussing on ERN, error related negativity).

Laboratory work is usually limited and limiting by its nature. It is certainly so in the study of CS: CS in the neuroimaging lab is a far cry from switching “in the wild” (see Gullberg, Indefrey, and Muysken, this volume). To the best of our knowledge, neuroimaging studies have not systematically taken into account why or when CS occurs in natural speech, and designed the stimuli accordingly. For example, in naturally spoken sentences, CS does not occur randomly. Yet, no neuroimaging designs have directly compared a code switch at a natural juncture versus one that would never occur. ERP components such as the CPS (closure positive shift) and ERN, in particular, could be used to examine the processing consequences of CS at various positions between and across constituents, phrases, clauses, and other boundaries in written and spoken texts.

Investigations of inhibition in language switching would do well to include a condition requiring switching in a task that has nothing to do with language. Such data would help us to determine whether the neural circuitry involved in language switching is unique to bilinguals and language switching or shares some if not all of its features with other switching mechanisms in bilinguals and monolinguals alike. Moreover, to the extent possible, investigations of language switching would do well to compare switching in both directions, to examine the claim that it is easier to switch from L2 to L1 than vice versa. Related to this issue, some researchers report that bilingual children become exceptionally good at ignoring distractive information and at switching between different cognitive tasks compared to monolingual children (e.g., Bialystok, 1999; Bialystok & Martin, 2004; Bialystok & Shapero, 2005). They hypothesize that the reason behind this is the development of enhanced cognitive control mechanisms in bilingual children to be able to handle switching and attentional control demands from an early age. According to this suggestion, training in switching languages seems to generalize to other cognitive domains. Brain imaging techniques could become a useful tool to test this hypothesis.

An interesting population of study in the field of CS is that of professional interpreters (Petsche *et al.*, 1993; Proverbio *et al.*, 2004; Rinne *et al.*, 2000). Some professional interpreters have commented on the fact that they can no longer read a novel and enjoy it just as it is written. By their own account, they feel compelled to think of how that sentence/word/expression would have been conveyed in another language. The systematic study of their brain functioning compared to bilingual controls might inform us about possible differences between trained and untrained ‘switchers’. Such data in turn might aid in the development of criteria for determining what cognitive skills are needed to become a professional interpreter (switcher).

Further exploration of CS brain reaction could be especially informative with respect to the functional organization of lexical and semantic knowledge in bilinguals. Not every concept that is lexically coded in one language is coded in the other (in fact, this is an important reason for borrowing a word from an alternative lexicon). Translations are often not exact equivalents. The encyclopaedic knowledge that a speaker possesses about a certain word will seldom exactly match the connotations s/he has with the translation equivalent exactly (Backus, 1996), especially with regard to their “shades of meaning”. Languages may express a particular concept in more than one way. One can imagine investigations of these issues using the N400 component. How does the degree of overlap in meaning between a word or phrase in L1 and L2 influence its integration into a sentence context? Can, and if so, how quickly do words in a language acquire new shades of meaning under the influence of the connotations of its equivalent in the alternative language (“loan semantics”). Systematically manipulating two or more languages with brain imaging measures will definitely enrich our knowledge of how bilingual brains store, use, interchange, and convey meaning using alternative codes or alternate the code at use. After all, languages often evolve due to influences from other languages during language-contact phenomenon such as CS.

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