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Neurolinguistic Approaches to Spanish as a Heritage Language

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Introduction

The field of neurolinguistics—i.e., the study of how language is processed and represented in the human brain—finds itself at the intersection of the fields of neuroscience, linguistics and cognitive science more generally. The history of neurolinguistics can be traced back as far as the 1860s with Paul Broca’s seminal observations and descriptions of patients with speech impairments caused by brain lesions to the posterior inferior frontal gyrus. This region later became known as Broca’s area, one of the most studied language-related brain regions (Dronkers, Plaisant, Iba-Zizen & Cabanis 2007). While the field has continued to gain insight into how the brain processes language throughout its history, it has been revolutionized in the last forty years as a result of developments in neuroimaging techniques (Ingram 2007). The vast majority of this recent work has examined language processing in monolingual speakers (see, for example, reviews by Poeppel & Hickok 2004 and Ross 2010), and has resulted in a rich body of literature which includes the investigation of a number of issues, including the time-course of both semantic and syntactic language processing (Friederici 2002), the neural correlates underlying semantic processing (Binder, Desai, Graves & Conant 2009), as well as how words are recognized (Lee & Federmeier 2012), comprehended (Kaan & Swaab 2002) and produced (Indefrey 2011).

More recently, neurolinguistic research has expanded to focus on language processing in bilingual individuals, examining how and where a bilingual’s two languages are represented in the brain, and how a bilingual manages these two systems during real-time language processing (see Kroll & Sunderman 2003 and Kroll, Bobb & Hoshino 2014 for relevant reviews). Heritage speakers (HSs) constitute a unique type of bilingual with regard to their profile of (a) age of exposure and (b) experience and proficiency with their two languages. In particular, HSs generally have an early age of acquisition of both their home language (their L1) and the majority language (their second language or L2), with increasing exposure to the L2 upon entering schooling, and possibly reduced exposure to and concomitant proficiency in their L1 at this time. Thus, the investigation of HSs can shed light on how a number of age- and experience-related factors may influence language processing. In fact, multiple researchers (e.g., Montrul 2011, 2012; O’Grady, Kwak, Lee & Lee 2011) have pointed out that this population is uniquely poised in terms of their potential to answer theoretical questions about language acquisition.
Research has just begun to explore language processing in the brains of heritage speakers using neurophysiological measures, which can provide insights into real-time processing and neural representation of language.

In this chapter, we will focus on three neurolinguistic methods that have been used to investigate Spanish as a heritage language either during language recognition or production tasks: functional magnetic resonance imaging (fMRI), functional near infrared spectroscopy (fNIRS) and event-related potentials (ERP). These techniques measure changes in blood-flow and electrical activity in the brain and shed light on the neural substrates and/or time course of language processing. These methods may thus be particularly informative as they provide insight into the mind-brain in ways that traditional behavioral linguistic assessments (e.g., acceptability judgment tasks, production tasks, recognition tasks) and psycholinguistic assessments (e.g., reaction time data) may not allow.

The remainder of this chapter will be organized as follows. First, we will review current neurolinguistic research on Spanish as a heritage language. Within this review, we will briefly describe each of the neurolinguistic research methods that have been used to investigate this topic. Second, we will explore how neurolinguistic models of language acquisition and representation may account for HSs’ language processing based on the evidence from current research. Finally, we will discuss open questions for future research and discuss how neurolinguistic methodologies can be applied to important theoretical questions surrounding language acquisition generally and heritage language in particular.

**Review of neurolinguistic research on Spanish as a heritage language**

Our initial literature search identified very few neurolinguistic studies that reported to investigate heritage language. We thus performed literature searches in LLBA and PsycINFO databases for “heritage” as well as “bilingual”-focused studies, together with one of several neurophysiological methods: fMRI, fNIRS, ERP, Positron Emission Tomography (PET), Magnetoencephalography (MEG) and Diffusion Tensor Imaging/Diffusion Magnetic Resonance Imaging (DTI/DMRI). We found that, when examining the descriptions of participants, several of the “bilingual” studies in fact appeared to investigate HSs of Spanish. We followed the characterization of Bolger and Zapata (2011: 1) in operationalizing HSs of Spanish as those who “are exposed to Spanish or both English and Spanish since birth or before the age of 5, but receive most of or all their schooling in English.” In cases that were unclear, we contacted the authors to determine whether the participants could be classified as HSs of Spanish. Thus, we were able to identify seven published studies that have investigated the processing of Spanish as a heritage language with neurolinguistic methods, and in addition we include an as yet unpublished study of our own. These studies used only three different neurophysiological methods: fMRI, fNIRS and ERP.

**Functional Magnetic Resonance Imaging (fMRI)**

fMRI is a neuroimaging technique that reflects “changes in blood oxygenation and flow that occur in response to very localized changes in neural activity” (Rodden & Stemmer 2008: 62). Specifically, magnetic fields are used to measure hemodynamic changes known as blood oxygenation level dependent effects (the BOLD signal). fMRI has excellent spatial resolution (i.e., activation can be localized to regions of the brain on the order of millimeters), whereas its temporal resolution is on the order of seconds due to the time-course of the hemodynamic response to neural activity. Thus, the chief advantage of fMRI in language study is its ability to identify
regions that are involved in language processing. Typically, fMRI language studies use blocked designs, where tasks (or processing of particular types of stimuli) are performed over blocks of time, and brain activity over the entire block is measured and compared to activation either during rest or during a baseline task. Some fMRI research has also used event-related designs, in which it is possible to intermix stimuli or tasks of different types, and statistically separate and measure the activation related to each one.

We were able to identify five fMRI studies that investigated the processing of Spanish in heritage speakers. Three of these examined language switching, one investigated single-word reading, and one studied sentence-level processing. In the first of the language switching studies, Hernandez, Martinez and Kohnert (2000) used fMRI to investigate language switching during a naming task in bilingual speakers who were in fact HSs of Spanish. Participants (4 female, 2 male) were right-handed bilinguals with a mean age of 23.5 (SD = 3.21) who learned both Spanish and English prior to age 5. They had on average 16 years of formal study of English, compared to 3 of Spanish. Participants’ vocabulary was assessed with the Boston Naming Test, which consists of 60 line drawings graded in difficulty, which participants are asked to name. They scored higher in English (mean = 54) than Spanish (mean = 40), and thus were deemed to be stronger in English than Spanish. In the study, participants performed a cued picture-naming task, in which a visual cue (the written word “say” in English or “diga” in Spanish) indicated which language participants should use to respond. The two conditions were blocked (cues all in one language) or mixed (alternating languages). Data were collected from pre-defined regions of the brain spanning the dorsolateral prefrontal cortex and the supra-marginal gyrus. Analyses revealed no differences in areas activated or in intensity of activation in the blocked conditions (English vs. Spanish). The mixed condition, however, evidenced increased activation in the dorsolateral prefrontal cortex as compared to the blocked conditions. The authors interpreted this activation as being tied to language switching, which they viewed as part of a general executive attentional system.

Hernandez (2009) also examined language switching during a naming task in a group of HSs of Spanish via fMRI. Participants in this study (5 female, 7 male) were right-handed and had a mean age of 21.4 (SD = 1.75). They had acquired Spanish as their first language and were exposed to English “upon entering school at age 5” (Hernandez 2009: 135). They scored higher on the Boston Naming Test in English (mean = 47) vs. Spanish (mean = 32), and thus were considered to be dominant in English. In this study, picture-naming was covert (i.e., silent), and analyses were not limited to pre-defined regions of interest, but rather a random effects analysis was employed across all scanned brain regions, which included nearly the entire brain (i.e., a much broader analysis as compared to the above-mentioned study). Results were taken to replicate and extend the previous findings through the examination of additional brain regions. In particular, there was increased activity in right dorsolateral prefrontal cortex during language switching, but this activation was found to extend farther (to the right precentral gyrus, the supplementary motor area, and the right superior parietal lobule). This finding was taken to indicate that not only the prefrontal cortex (implicated in executive function) but a larger network is in fact recruited for language switching. The authors suggested that these areas are involved in executive function as well as in articulatory and motor planning, and that they could be recruited in the switching task either to inhibit the non-target language or to activate the target language response, or both. Results also revealed differences in areas of activation between languages in blocked conditions, whereas in the prior study, no such differences were found (for English vs. Spanish, there was increased activity in right post-central gyrus, superior temporal gyrus, hippocampus, insula, and pre-supplementary motor areas; for Spanish vs. English, in left hippocampus, thalamus, amygdala, inferior frontal gyrus, and right anterior insula).
Note that increased activity for the L1 (Spanish) was largely left-lateralized whereas increased activity for the L2 (English) was right-lateralized. It was not entirely clear how to interpret these findings, but the authors suggested that there could be differences in sensorimotor learning based on age of acquisition, and that the L1 may be more closely linked to word knowledge and emotional content.4

A third fMRI study of language switching during a naming task was conducted by Weissberger, Gollan, Bondi, Clark and Wierenga (2015). Participants (15 females, 5 males) were right-handed and had a mean age of 20.45 (SD = 1.9). They were exposed to Spanish very early (mean age = 0.3 years, SD = 0.5) and English later (mean = 5.1 years, SD = 3.5). Based on reaction times and error rates for a picture naming task, 90% were classified as English dominant. By self-report, 70% considered themselves English dominant, 15% balanced, and 15% Spanish dominant. In this study, participants performed (a) a cued language-switching task in which they had to covertly name numbers (1–9) in Spanish or English (cued by a Mexican or American flag), and (b) a cued color-shape-switching task in which they had to name either the color or shape of a form (cued by a rainbow-colored rectangle or a series of shapes, respectively; all participants chose to carry out this task in English). The fMRI design was hybrid (both blocked and event-related). Analyses examined neural responses to trials of three types as compared to rest: (a) single trials (a trial in the blocked condition, where the task did not alternate), (b) stay trials (a trial of the same type as the preceding trial during a mixed block), and (c) switch trials (a trial of the opposite type as the preceding trial during a mixed block). Analyses also compared brain responses during the language task as compared to the color-shape task for these three trial types. Results revealed few differences in activation between responses to the language vs. color-shape task on switch and single trials, but large differences on stay trials, with the activation being more widespread for the color-shape than the language task. This was taken to suggest that (a) switching mechanisms are shared across linguistic and non-linguistic domains, and (b) bilinguals are more efficient at sustaining the inhibition of the non-target language (and thus recruit fewer neural resources) in the stay trials of the language task as compared to the stay trials in the color-shape task. The authors suggest that this efficiency might come from bilinguals’ need to suppress a non-target language when not switching languages.5

An fMRI study of single-word reading in HSs of Spanish was carried out by Meschyan and Hernandez (2006). Participants (7 females, 5 males) were right-handed, with an average age of 22.3 years (SD = 1.35) and had learned Spanish early (mean = 0.25 years, SD = 0.45) and English later (mean = 4.33 years, SD = 1.16). They had on average 15.6 years of formal study of English compared to 3.4 years in Spanish. Their average score on the Boston Naming Test was also higher in English (mean = 46.83, SD = 4.59) than Spanish (mean = 35.42, SD = 3.42). Self-assessments of language ability were also higher in English than Spanish, leading the authors to conclude that participants appeared more proficient in English than Spanish. In the experimental task, participants silently read blocks of words in Spanish or English while undergoing scanning. Results showed greater activation in Spanish (vs. English) of the articulatory motor areas in the right hemisphere (supplementary motor area/cingulate, insula, and putamen) and in phonological processing regions (left superior temporal gyrus). In English (vs. Spanish), there was greater activation in visual processing and word recoding regions, i.e., areas involved in converting letters to sounds (occipito-parietal border and inferior parietal lobe). The greater right hemisphere activation in Spanish was taken to reflect more effortful processes given that Spanish was participants’ weaker language. The differences in phonological and visual processing activation between languages was attributed to the orthographic transparency of Spanish (leading to more phonological processing) vs. the opacity of English (leading to more visual processing). Together these results suggest that there are differences in processing an HS’s two
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languages, which may be related to differences in proficiency between the languages as well as to differences in the orthographic transparency of the languages.⁶

Kovelman, Baker and Petitto (2008) investigated processing of sentences with fMRI during a syntactic “sentence judgment task.” Participants, who were heritage speakers (the “bilingual” group; 7 females, 4 males), were right-handed and had a mean age of 19 years (range = 18–22 years). All were exposed to Spanish from birth, and to English between birth and age 5. All learned to read in English at school and in Spanish at home. Five participants had some formal bilingual education prior to university, and all had at least one formal Spanish class. Participants considered themselves to be equally fluent in both languages and equally active in both communities, and achieved at least 80% accuracy in both languages on a language screening task called the Language Competence/Expressive Proficiency test. In the study, participants read sentences in a blocked design (English in one block and Spanish in the other) and gave plausibility judgments after each sentence. The authors exploited specific differences in the languages, in particular differential reliance on word order vs. morphosyntax, to explore whether there were differences in neural responses to the two languages.⁷ Participants were told in which language each block would be presented (Spanish or English) in order to induce a monolingual processing mode, rather than a switching or bilingual mode. Stimuli included both plausible and implausible sentences with either object- or subject-relative clauses (referred to as OS and SO, respectively). It was predicted that if bilinguals have differentiated linguistic systems, they should show a smaller difference in brain activity between the two types of sentences in Spanish (where word order is less informative) than in English (where it is more informative, and where OS sentences are more common and should be easier to process than SO sentences). Results indicated that in English mode, there was indeed greater intensity of activation for SO (more difficult) than OS (easier) sentences. In Spanish mode, however, there were no differences in brain activity between SO and OS sentences. This evidence was taken to support the notion that these early bilinguals “have a differentiated neural pattern of activation for each language” (Kovelman, Baker et al. 2008: 166).⁸

In sum, the data from fMRI studies suggest that with regard to language switching tasks, HSs may engage executive control-related regions of the brain in order to activate the target language and/or inhibit the non-target language (Hernandez et al. 2000; Hernandez 2009). They may be especially efficient at sustaining inhibition of the non-target language as compared to inhibiting non-linguistic non-target responses (Weissberger et al. 2015), and this may be due to their experience with suppressing the non-target language when operating in a monolingual mode. With regard to brain activation during language processing, the research suggests that while there is apparently a large degree of overlap in areas of activation, HSs’ two languages may be differentiated on a fine-grained neurological level. This is suggested by the fact that HSs show differential intensity of activation for object- vs. subject-relative clauses in English but not in Spanish (Kovelman, Baker et al. 2008), and that they show differential activation between languages in articulatory motor regions, phonological processing regions and word recoding regions, which may be driven by either proficiency, orthographic transparency or both (Meschyan & Hernandez 2006).

Functional Near Infrared Spectroscopy (fNIRS)

fNIRS (also referred to as optical imaging or optical topography) is a non-invasive technique that measures hemodynamic changes in the brain via sensors at the scalp. These sensors detect near infrared light transmitted through neural tissue from sources also placed at the scalp; the scattering and absorption of this light depends on hemodynamic changes that reflect brain
activity. The temporal resolution of fNIRS is more fine-grained than that of fMRI but less than that of ERPs (see later), whereas its spatial resolution is less precise than fMRI but more precise than that of ERPs (on the order of centimeters). Thus it can be considered a middle-of-the-road technique with regard to both temporal and spatial resolution. Note, however, that fNIRS research usually focuses only on selected regions of the scalp near where the sources and sensors are placed. It is also noteworthy that fNIRS equipment is portable and (unlike either fMRI or ERP) amenable to movement by participants during the completion of experimental tasks (see Quaresima, Bisconti & Ferrari 2012 for a review of fNIRS used with language paradigms).

We were able to identify only one study of Spanish as a heritage language employing this relatively new method (Kovelman, Shalinsky, Berens & Petitto 2008). Participants (6 females, 4 males) were right-handed and averaged 20 years of age. They had been consistently exposed to both English and Spanish by the age of 5, with half exposed to both Spanish and English at home from birth, and half exposed to only Spanish at home from birth and to English in daycare or kindergarten starting at 3–5 years of age. They learned to read in English from ages 5–7 and in Spanish from ages 5–12. All participants were screened for proficiency in English and Spanish on standardized grammaticality judgment tasks in each language, and all were deemed to have “high, monolingual-like, language proficiency in each of their two languages” (Kovelman, Shalinsky et al. 2008: 1459), having scored at least 80% on each. In the study, these bilingual participants were tested (as were a control group of monolingual English speakers) on semantic processing with a version of the Pyramids and Palm Trees Task. In this task, each trial presented a sequence of two words, followed by a picture that corresponded to either the first or second word; participants responded via button-press to indicate which word matched the picture. There were four blocked conditions: monolingual English, monolingual Spanish, bilingual with language integration (one word in Spanish and the other word in English within each trial) and bilingual with language alternation (languages alternated randomly between trials but only one language within each trial). Results indicated that in monolingual mode, HSs (as compared to monolingual English speakers) showed greater intensity of activation in areas tied to verbal working memory and attention (dorsolateral prefrontal cortex and inferior frontal cortex). Moreover, within the HS group, in bilingual mode (as compared to monolingual mode), results indicated that there was greater recruitment of these same structures in the right hemisphere. These results were taken to support a view in which bilinguals recruit neural resources differentially from monolingual speakers, and in particular recruit regions that have previously been tied to language switching. Interestingly, this increased activation was observed in HSs not just in bilingual mode as compared to monolingual mode, but also in monolingual mode as compared to monolingual speakers.

**Event-Related Potentials (ERP)**

During human cognition, there are electrical signals embedded within the electroencephalogram (i.e., recordings of electrical activity at the scalp) that are affected by language processing. When these signals are time-locked to specific stimuli and averaged over numerous similar trials, the brain’s electrophysiological response (i.e., changes in the brain’s electrical activity) to a specific cognitive event can be observed. These time-locked signals are known as event-related potentials (ERPs), and the characteristic positive and negative potentials produced are known as components (see Handy 2004 and Luck 2014 for overviews of the ERP technique). ERPs are particularly well-suited for examining language processing as this method has very precise temporal resolution (on the order of milliseconds). Moreover, various components have been identified in L1 ERP research as being reliably elicited by specific types of language processing,
though these components are not unique to language (see Kutas & Federmeier 2011; Steinhauer & Connolly 2008 for reviews on monolingual language processing). The processing of lexical/semantic information is usually indexed by a negative potential that occurs approximately 400 ms after the onset of a stimulus (such as a semantic anomaly) and is typically maximal at central and parietal regions of the scalp (the N400; Kutas & Federmeier 2011; Kutas & Hillyard 1980). The brain’s most commonly reported electrophysiological response to the processing of grammatical information is a positive potential occurring approximately 600 ms after the onset of a grammatical anomaly and is typically largest at central and posterior regions of the scalp (the P600; Osterhout & Holcomb 1992). This component may or may not be preceded by an earlier left and/or anterior negativity (the LAN) and may additionally be accompanied by a later anterior negativity (Neville, Nicol, Barss, Forster & Garrett 1991). Generally, research with bilinguals has shown that the higher the level of proficiency and the more experience with a language, the more L1-like their ERP signatures for grammatical conditions are, whereas ERP signatures in response to semantic errors are L1-like from much earlier on in the learning process (McLaughlin et al. 2010; Steinhauer, White & Drury 2009).

We identified one published ERP study of Spanish as a heritage language in our search, and in this chapter, we also report a recent study of our own. Moreno and Kutas (2005) recorded ERPs to examine semantic processing in the dominant and non-dominant languages of two groups of Spanish-English bilinguals. One of these groups, the English-dominant group as established via the Boston Naming Test, was in fact a group of HSs of Spanish (personal communication). These participants (15 females, 5 males; right-handed except for one ambidextrous participant) had a mean age of 23 years (SD = 3). They had relatively early exposure to both Spanish and English, with 17 reporting exposure to Spanish at birth and all exposed to English by age 6. All underwent the majority of their schooling in English (personal communication). Dominance was operationalized as having a difference in scores between the two languages of at least 8 on the Boston Naming Test. Participants in this group scored on average 29 (SD = 8) in Spanish and 51 (SD = 6) in English (mean difference = 22; range of difference scores = 11–42) thus all participants in this group were deemed to be English-dominant. Participants also reported continued use of Spanish approximately 44% of the time with family and friends. In this study, participants completed a blocked sentence-reading task, in which they read a series of semantically congruent and incongruent sentences for comprehension (first in one language and then the other). Analyses found that the N400 peak latency (i.e., the amount of time from stimulus onset to the peak amplitude of this component) was delayed in the bilinguals’ less dominant language (Spanish) as compared to their more dominant language (English). Surprisingly, these results suggest that despite having exposure to Spanish from birth, HSs’ time course of semantic processing was unlike that of monolinguals, as reflected by the delay in N400 peak amplitude. This delay is typically found in L2 learners who are exposed to their L2 relatively later in life. The authors take this as evidence that age of acquisition alone cannot explain differences in processing shown in this group. Moreover, correlations evidenced between vocabulary proficiency and N400 peak latency suggested that proficiency may also play a crucial role in the latency of the integration of semantic information.

In a recent ERP study (Bowden, Issa & Morgan-Short 2015), we examined processing of both lexical and grammatical structures in the Spanish of HSs. Participants (11 females, 8 males) were enrolled in a university-level heritage language class. All were right-handed and their mean age was 21.1 years (SD = 3.1). They reported having acquired Spanish very early (mean = 0.6 years, SD = 0.8) and English a bit later (mean = 4.1 years, SD = 2.8). Most (n = 15) considered themselves dominant in English, and all had undergone the majority of their schooling in English. On average they rated themselves higher in speaking, understanding
and reading English (mean = 8.8 out of 10) as compared to Spanish (mean = 7.2). In the experimental task, participants read Spanish sentences (presented one word at a time) and made acceptability judgments. The stimuli consisted of intermixed correct and violation sentences of various types, including the following conditions: phrase structure and semantic conditions (taken from Bowden, Steinhauer, Sanz & Ullman 2013) and gender and number agreement conditions (taken from Bowden 2007). All sentences were constructed in a balanced paradigm following Steinhauer et al. 2009. These conditions are exemplified in Table 14.1. We included 40 sentences each for the phrase structure and semantic conditions, and 32 each for the gender and number agreement conditions (equally divided among masculine, feminine, singular and plural critical items).

EEGs were recorded during the sentence-reading task, across 32 electrodes and at a 512 Hz sampling rate, with impedances kept below 5 kΩ. ERPs were time-locked to the onset of the target word (underlined in Table 14.1) and a −200 ms baseline correction was applied. Time windows for analyses were determined by visual inspection of grand average ERPs. We performed standard analyses (ANOVAs with step-down analyses) across the whole group (grand averages) and additionally explored individual differences based on response dominance (following Tanner, Mclaughlin, Herschensohn & Osterhout 2013) in early and late time windows.

Behavioral responses indicated that as a group, all conditions were above chance level (d’s of 1.87 for semantic, 2.33 for phrase structure, 1.06 for gender and 0.87 for number). Regarding the ERP signatures, the semantic condition elicited an N400 (300–500 ms; see Figure 14.1). This result is consistent with what was found by Bowden et al. (2013) for L1 Spanish as well as for L2 speakers at low and advanced levels of experience and proficiency.

For phrase structure, there was an N400 (300–600 ms) followed by a small P600 (900–1100 ms) across the group; however, the P600 was significant at only one electrode. No significant ERP effects were found for gender, while for number, there was only a small negativity (400–600 ms) in the centro-anterior region. Note, these responses to grammatical violations do not correspond to typical L1- or L2-like responses. Subsequently, following Tanner et al. (2013), we examined individual variability in ERP responses. We characterized participants in terms of their effect magnitude (i.e., size of the effect, whether negative or positive) and response dominance (i.e., more negative or positive) over a specified centro-parietal region of interest in earlier and later time windows (see Table 14.2).

<table>
<thead>
<tr>
<th>Table 14.1 Sample stimuli sentences</th>
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<tbody>
<tr>
<td><strong>Condition</strong></td>
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| Semantic | La profesora espera ir en autobús a la #semana.  
‘The professor hopes to go by bus to the #week.’ | Tengo muchas **millas** que correr esta semana.  
‘I have many miles to run this week.’ |
| Phrase structure | Tengo que *millas muchas correr esta semana.  
‘I have to *miles many run this week.’ | |
| Gender | El lago es *tranquila* por la mañana.  
‘The lake_{m} is tranquil{m} in the morning.’ | El lago es **tranquil** por la mañana.  
‘The lake_{m} is tranquil{m} in the morning.’ |
| Number | El lago es *tranquilos* por la mañana.  
‘The lake_{m} is tranquil{m} in the morning.’ | |
Figure 14.1  ERPs for semantic condition (grand mean across all participants). Waveforms show ERPs to correct (solid line) and violation (dashed line) critical words recorded at electrode Pz, with negative plotted up. The arrow points to significant differences between responses to correct and violation critical words. Scalp maps show potentials (violation-correct) across early and late time windows.

Table 14.2  Time windows for individual ERP analyses

<table>
<thead>
<tr>
<th>Condition</th>
<th>Early</th>
<th>Late</th>
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<tbody>
<tr>
<td>Phrase structure</td>
<td>300–600 ms</td>
<td>900–1100 ms</td>
</tr>
<tr>
<td>Gender</td>
<td>400–600 ms</td>
<td>900–1100 ms</td>
</tr>
<tr>
<td>Number</td>
<td>400–600 ms</td>
<td>900–1100 ms</td>
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</table>

Figure 14.2  Scatterplots showing the distribution of N400 and P600 effect magnitudes across participants, averaged over a centro-parietal region of interest, for each condition (semantic, phrase structure, gender, number). Each dot represents a participant, with P600 magnitude (later time window) on the x-axis and N400 magnitude (earlier time window) on the y-axis. The best-fit line from a regression analysis is represented by a solid line, whereas the dashed line represents equal responses. Participants to the right of the dashed line are positive-dominant and to the left, negative-dominant.
As can be seen in Figure 14.2, in the semantic condition, the N400 effect magnitude (earlier time window) did not correlate with the P600 effect magnitude (later time window). In the three grammatical conditions, however, there was a negative correlation—that is, the larger a person’s N400 effect in the early time window, the smaller their P600 effect in the later time window tended to be, or vice-versa. In addition, it can be observed that the dashed line (the dividing line between a negative or positive response dominance), divides the participants roughly in half for all conditions except the semantic condition, in which all but two participants have predominantly negative responses. This indicates that there was significant variability in response dominance in the three grammatical conditions, but very little in the semantic condition. Thus we separately explored the responses of the positive- and negative-dominant participants for each grammatical condition.

In doing so, a very different picture emerged (see Figure 14.3). In brief, within each of the grammatical conditions (phrase structure, gender, number), the negative-dominant participants...
showed a significant N400 and the positive-dominant participants a significant P600. The N400 extended into the later time window in the gender and number conditions. Additionally, in the gender condition, the positivity started in the early time window as well. This pattern of results suggests that except for the semantic condition, there were underlying individual differences that were obscured by group averages. Recent research by Tanner and Van Hell (2014) has revealed that even within L1, morphosyntactic processing may show similar variability. Our results extend this finding to the heritage language context.

From the two ERP studies presented above, we can draw some preliminary conclusions regarding heritage language processing of Spanish at the sentence level. First, there is evidence from both studies that lexical/semantic processes in heritage language rely on the same neurocognitive systems as monolinguals and L2 learners (as seen in findings from previous studies), given that processing semantically incongruent stimuli elicits N400s in both studies. There is also evidence that lexical/semantic processing in real time may be delayed in the heritage language as compared to HSs’ more dominant L2 (Moreno & Kutas 2005). In addition, there is evidence of variability in processing among HSs for grammar (Bowden et al. 2015). It remains to be seen to what extent this variability and the factors that may account for it (e.g., proficiency, experience, cognitive resources) differ from or correspond to variability in L1 and L2.

In sum, it appears that from the fMRI and fNIRS research reviewed earlier that HSs exhibit a high degree of overlap in neural substrates that underlie their two languages, even while they show some differential activation of brain regions when using one language as compared to the other. Moreover, they show increased activation of particular regions of the brain apparently related in part to executive function when switching between their two languages. In fact, HSs may be particularly adept at inhibiting a non-target language as compared to non-linguistic inhibition. These findings echo previous research on simultaneous bilinguals, indicating that bilingualism has positive effects on cognitive function, specifically with regard to inhibition (Kroll & Sunderman 2003). In the ERP studies reviewed earlier, HSs showed neural signatures in Spanish that have been reported previously for both L1 and L2 processing, although the time-course of their lexical processing may be somewhat delayed. Together, these results suggest that HSs of Spanish resemble native monolinguals in some ways but also differ from them in fine-grained ways in the processing of their heritage language. At least some of these differences appear to be related to management of two languages in the brain.

**Theoretical models**

Although the studies we have summarized are all related in that they investigated heritage language processing through neurolinguistic methods, they differ in their broader conceptualization of how language is represented and processed in the brain and the type of research questions they aim to answer. Examining the theoretical models that motivated these studies can provide insights into how to better understand and contextualize the results reported, as well as yield questions to be asked in future research.

At least in broad strokes, the fMRI (Hernandez 2009; Hernandez et al. 2000; Kovelman, Baker et al. 2008; Meschyan & Hernandez 2006; Weissberger et al. 2015) and fNIRS (Kovelman, Shalinsky et al. 2008) studies reported earlier appear to provide evidence consistent with the cognitive control model (Abutalebi 2008; Abutalebi & Green 2007, 2008). This model suggests that while bilinguals largely engage similar neural substrates in L1 and L2 processing, bilinguals may engage more extended neural areas in L2 processing, especially at lower levels of proficiency, because increased cognitive control is necessary for processing a language that is weaker. Thus,
this interpretation holds that larger areas of activation observed for L2 processing (especially in the left prefrontal cortex) are not due to the need to engage more areas for linguistic processing per se, but rather due to increased activation of brain regions involved in controlling the language networks when using the weaker language. This control seems to include not only activation of the weaker language but inhibition of the stronger language, which would be especially plausible in contexts in which both languages are active, such as in language-switching tasks.

A more recent version of the cognitive control model, called the adaptive control hypothesis (Green & Abutalebi 2013), makes additional predictions about how control mechanisms are activated based on the interactional context that a speaker most often encounters. This model distinguishes between three interactional contexts: (a) the single-language context, in which a speaker uses one language in one environment (e.g., at work) and their other language in a different environment (e.g., at home); (b) the dual-language context, where “both languages are used but typically with different speakers” (Green & Abutalebi 2013: 518); and (c) the dense code-switching context, “in which speakers routinely interleave their languages in the course of a single utterance,” (Green & Abutalebi 2013: 518). HS data may be able to directly test predictions made by this hypothesis as HSs may fall into any one of the above-mentioned interactional contexts depending on their linguistic profile and the linguistic community to which they belong. In addition, this model could potentially make predictions that would differ depending on other task and speaker characteristics. For example, on tasks that HSs are more adept at performing (for example oral vs. written or less vs. more metalinguistic), the model would likely expect less engagement of these control networks as compared to tasks on which they are less proficient. These are questions that future research on heritage language could address by employing neurophysiological methods.

Another prominent theoretical model that may lend itself to interpreting the results of some of the studies summarized earlier, as well as to making novel predictions with regard to heritage language, is the Declarative/Procedural model (see Ullman 2001, 2005, 2015a, 2015b for more details about the model itself as well as for reviews of evidence supporting the model). This neurobiologically informed model of language generally holds that two memory systems, declarative and procedural memory, underlie much of language learning, processing and use. In particular, the model posits that idiosyncratic knowledge of language (including lexical knowledge and knowledge of irregular forms) must rely on declarative memory, where learning depends largely on the hippocampus, but once consolidated, knowledge may come to rely on related cortical areas. Grammatical knowledge (especially knowledge of rules and sequences), on the other hand, may rely on procedural memory, which is based in frontal and basal ganglia circuits in the brain and is taken to be a compositional system. Because learning in declarative memory is relatively fast, learning of both lexical and grammatical forms may initially depend largely on declarative memory, for both children and adults. However, with increasing experience and proficiency with a language, procedural knowledge of the grammar gradually builds up and grammatical processing may come to rely on the procedural system. Importantly, learning in procedural memory is better in children than adults. Thus, it should be easier to acquire grammar procedurally in early-learned L1 than later-learned L2, and later-learned languages may tend to rely more on declarative memory even for knowledge that in L1 may rely on procedural memory.

The Moreno and Kutas (2000) and Bowden et al. (2015) studies are both consistent with predictions that this model would make, although the model has not been specifically extended to heritage language and it is not yet entirely clear to what degree ERP components directly reflect declarative or procedural memory systems. In both studies, semantic conditions reveal N400 responses, which have been argued to depend on declarative memory (Ullman 2004).
Further, the results from Bowden et al. (2015) highlight the variability among HSs in their neural signatures for the processing of grammar, which may reflect, at least in part, variability in reliance on declarative and procedural memory systems for this type of processing, which is within the scope of the Declarative/Procedural model. Whether this variability in ERP responses in fact reflects differential reliance on declarative and procedural memory systems remains to be investigated. Moreover, the model could make predictions with regard to factors that should explain the variability in responses, in particular, age, amount and type of exposure to the target language, individual differences in declarative and procedural memory, and sex, among others.

Bolger and Zapata (2011) have explored how the Declarative/Procedural model could be extended to the case of heritage language. Two key issues in heritage language that they consider are those of attrition and incomplete acquisition of the often less-used L1. As they point out, L1 attrition could be explained by this model especially in the case of declarative knowledge, since it is more susceptible to changes in frequency in the input (e.g., reduced exposure to L1 for HS speakers). Moreover, incomplete acquisition of grammar could also be predicted by this model, if, for example, not all aspects of the heritage grammar have been proceduralized when the amount of input is drastically reduced, which might happen when heritage learners of Spanish begin attending school in English and spend less time immersed in Spanish. Thus, for example, as Bolger and Zapata suggest, perhaps only “core” aspects of grammar have been acquired at this point, but not “peripheral” aspects (which might lead to incomplete acquisition, another key issue in heritage language). Specific predictions would depend on when particular aspects of grammar are typically learned as well as when exposure to English begins, and whether this reduces exposure to Spanish and inhibits L1 learning. Moreover, if, as they suggest, procedural knowledge is less susceptible to environmental changes than declarative knowledge, then grammar that is acquired and proceduralized early should be less susceptible to attrition than either grammar that is acquired later and not proceduralized, or declarative knowledge. Thus, we might expect that early-acquired grammar would be L1-like in its neural representation and signatures, whereas neural responses to later-acquired grammar (i.e., that which might show incomplete acquisition) might be less like that of monolinguals and might show increased reliance on declarative memory. In addition, if peripheral aspects of grammar depend more on semantics (i.e., grammar governed by the syntax-semantics interface) and thus rely more on declarative memory, then for this reason in addition, peripheral aspects of grammar might be more susceptible to erosion (and thus might not be native-like in terms of neural processing). Thus, this model may predict both lexical and grammatical attrition and/or incomplete acquisition, with lexical knowledge generally being more susceptible to such effects than grammatical knowledge, but with later-acquired grammar being more susceptible than early-acquired grammar. These predictions could be tested through the use of neurophysiological research methods.

**Future directions for research**

In addition to testing predictions of the above models as extended to the heritage language context, there are many fruitful areas of neurolinguistic research that would allow us not only to better understand this unique population but also to better understand language acquisition and processing more generally. Here we provide some suggestions for such future neurolinguistic research. To begin with, heritage languages can be more fully investigated in their own right in order to understand how they are acquired, represented and processed. Neurolinguistic methods such as ERP, fMRI and fNIRS could also be used to explore whether HSs process language similarly to or different from both L1 and L2 speakers of different types. Additionally, they
could provide a window for investigating theoretical questions about what aspects of language have undergone attrition vs. incomplete acquisition, questions that have so far been examined exclusively with behavioral and psycholinguistic techniques (see Montrul 2008). These questions could be examined by testing HSs’ neural signatures of processing at different points in their lifespan (thus probing what has been acquired and may be subject to attrition) as well as by comparing HSs to matched monolingual Spanish speakers and balanced bilinguals.

In addition, HSs may contribute to our understanding of the roles of age of acquisition and proficiency in language processing. In the field of second language acquisition, it is widely accepted that age of acquisition has an important effect on L2 processing and performance. However, the case has been made that other factors such as L2 use, L2 proficiency or L1–L2 pairing may in fact be more important than age of acquisition in affecting whether or not L2 learners demonstrate native-like language processing or performance (e.g., Birdsong & Molis 2001). That said, there are limitations to investigating adult L2 learners alone in probing these questions. By definition, L2 learners have a later age of acquisition, thus limiting researchers’ ability to investigate the age factor. Furthermore, L2 speakers with native-like proficiency are not abundantly available for research in foreign-language learning contexts. HSs, on the other hand, have early experience with both languages, and often high levels of proficiency in their heritage language, though it may be lower than that of monolingually raised native speakers. Thus the study of HSs using neurophysiological methods would elucidate how such factors as dominance, use and proficiency affect language processing while holding constant an early age of acquisition.

Another avenue for future research to pursue is to employ neurophysiological methods to investigate how speaker and task characteristics together influence processing. In the case of HSs, research could explore why HSs tend to show advantages on oral and more implicit tasks as compared to written and more metalinguistic tasks by investigating neurocognition during such tasks. Moreover, these methods could shed light on questions related to cognitive control. For example, some previous ERP studies with simultaneous bilinguals (but not HSs to our knowledge) have identified modulations in specific ERP components that appear to be related to language switching, and thus might be tied to cognitive control (e.g., Jackson, Swainson, Cunnington & Jackson 2001, and Proverbio, Leoni & Zani 2004). Future research could investigate this issue in HSs of Spanish.

Besides using the above-mentioned neurophysiological methods in new ways to investigate heritage language processing and language acquisition questions more generally, there are a number of additional neurolinguistic methods that, to our knowledge, have not been used to study the processing and neural correlates of Spanish as a heritage language, such as MEG, DTI or PET (see Rodden & Stemmer 2008 for a review of these methods). While each neurophysiological method has unique strengths and weaknesses, the main drawback of many of them is cost. In many cases, interdisciplinary research collaborations can provide language researchers with access to needed technologies and expertise to analyze heritage language processing. Ultimately, neurolinguistic data on heritage language processing should provide complementary and converging evidence to that of behavioral and psycholinguistic methods to gain a more holistic understanding of heritage language in all its complexity.

Notes


2 Note that the amount and precision of statistical information presented in this chapter reflects what was reported in each study, for example whether or not standard deviations were included, and the number of decimal places reported.
Neurolinguistic approaches

3 In a behavioral version of the task, performed prior to fMRI and with auditory cues (‘say’ or ‘diga’), reaction times (RTs) were measured. Participants responded faster in English (in both blocked and mixed conditions), whereas overall, they were faster on blocked than mixed conditions. Thus it was faster for HSs to access English (and/or cost them more time to suppress English while naming in Spanish), and language switching was also costly in terms of RT.

4 In this study, the RT results differed from the previous study; these HSs showed faster (and more accurate) naming in Spanish than English. Also, though the RT difference between mixed and blocked conditions was in the expected direction, it was not statistically significant. It is not clear what these differences should be attributed to. There might be differences in the dominance and/or proficiency of the participants between the two studies, or there may have been methodological differences in the naming task and/or stimuli.

5 RT analyses of an overt task performed prior to the fMRI task showed a cost for both mixed and switch trials, with a slightly greater cost for switching in the language task than the color-shape task.

6 Participants were slower at naming in Spanish on a behavioral version performed prior to fMRI.

7 They also investigated differences between monolinguals’ and bilinguals’ processing of English, which is not discussed here.

8 Analyses of RTs to the judgment task showed that HS were slower in Spanish than English overall, and were slower on OS sentences in Spanish than in English. In addition, they were faster (like English monolinguals) on plausible than implausible sentences.

9 The task was done both in auditory and visual modes, which were combined in analyses.

10 Note, however, that ERPs are only measured at the scalp. Although components have characteristic scalp distributions and functional interpretations have been made for many components based on the processes that elicit them, there is no straightforward way to localize the underlying source(s). For more information, see especially chapter 2 of Nunez and Srinivasan (2006).

11 An IIR Butterworth filter with a highpass frequency of .1 Hz and a low-pass frequency of 20 Hz was applied to the data offline, and trials contaminated with artifacts were excluded from analysis.

12 In addition, we performed all analyses (both grand mean and for response dominance) for each condition with a consistent early time window (300–600 ms) for the sake of comparability across conditions. The pattern of results was almost identical to that reported above. In the grand mean analyses with this early time window, the same components were evidenced, except that under the new analyses, the small early negativity in response to number violations was not significant.

13 Results from the correlation analysis examining the relationship between the N400 and the P600 effect magnitudes with the consistent early time window also produced an identical pattern of results, with the semantic condition yielding a non-significant correlation and the grammatical conditions resulting in significant negative correlations.

14 With regard to response dominance, analyses with the consistent early time window classified participants into the same groups as previously, except that one additional participant was classified as positive-dominant for semantic violations. Thus we again performed analyses by response dominance groups for all conditions except semantic, and again, the same components were evidenced, with one exception: the positivity for the number condition extended into the earlier time window.

Further reading


Includes chapter on Declarative/Procedural model of Ullman as well as other theories of second language acquisition that may be relevant to the heritage context.

### References


Neurolinguistic approaches


