# *Chapter 14*
# Sentences in the Brain: Event-Related Potentials as Real-Time Reflections of Sentence Comprehension and Language Learning

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## 14.1 INTRODUCTION

From the perspective of a person trying to understand a sentence, language is a continuous flow of information distributed over time. Somehow, the listener translates this stream of information into discrete and rapidly sequenced units of sound, meaning, and structure, and does so in real time, that is, nearly instantaneously. The results of these complex analyses are then integrated into a single coherent interpretation, even in the presence of considerable ambiguity.

The challenge facing us is to account for how people accomplish this. Asking the listener or reader for an answer to this question provides little useful information; the relevant processes are not generally available to conscious reflection. We must therefore rely on other methods of investigation. One might surmise that the ideal method would mirror the properties of comprehension itself (Osterhout, McLaughlin, & Bersick, 1997). The ideal method should provide continuous measurement throughout the process of understanding a sentence, have a temporal resolution exceeding that of the relevant processes, and be differentially sensitive to events occurring at different levels of analysis (phonological, syntactic, semantic, etc.). Furthermore, language comprehension is clearly a function of the human brain. Theoretical accounts of some of the most fundamental questions about human language (e.g., the ability of children to acquire language, and the effects of age on language-learning ability) rely explicitly on biological explanations. Compelling tests of these hypotheses necessarily require biological measurement. For these and other reasons, the ideal method should also provide a means for relating the obtained data to brain function.

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These properties of the ideal tool amount to a formidable methodological challenge. Unfortunately, few of the available methods have all of these properties, and the absence of even one property can limit significantly the utility of the method. For example, eyetracking provides continuous measurement during comprehension and has been quite useful for modeling certain aspects of reading and spoken language comprehension. However, eye movements respond similarly to events occurring at different levels of linguistic analysis; for example, eye fixations and regressions occur following an anomaly at any linguistic level. Furthermore, eyetracking does not provide any direct information about how language processing is instantiated in the brain. Functional neuroimaging techniques (e.g., PET and fMRI) do provide evidence concerning the relationship between language and brain and have proven helpful in revealing the neurobiology of certain cognitive functions (e.g., visual perception; cf. Tootell et al., 1998). However, nearly all of the currently available imaging methods suffer from a temporal resolution (> 1 s) that is at least an order of magnitude worse than the presumed temporal resolution of the processes of interest (tens and hundreds of milliseconds). The consequences of this and related limitations will be discussed in later sections of this chapter. (Further discussion of the properties of these methods can be found in Mitchell, chapter 2, this volume.)

One method that approximates the ideal method is the recording of event-related brain potentials (ERPs) elicited during language processing (Osterhout et al., 1997). ERPs are scalp-recorded changes in electrical activity that occur in response to a sensory, cognitive, or motor event (Rugg & Coles, 1995; van Berkum, chapter 13, this volume). ERPs are thought to reflect the summed, simultaneously occurring postsynaptic activity within neocortical pyramidal neurons. Topographical features of the ERP are referred to as components and can be described in terms of polarity (positive and negative), amplitude, onset, peak latency, and scalp distribution. ERPs provide a millisecond-by-millisecond record of the brain's electrical activity during the process of interest. ERPs are multidimensional (varying in polarity, latency, source configurations, etc.). Because they are direct reflections of brain activity, ERPs offer the prospect of tying cognitive theories of sentence processing more closely to the underlying neurobiology.

These prospective advantages are insignificant unless ERPs have the necessary sensitivity to the processes of interest. The goal of this chapter is to selectively review evidence (primarily from our laboratory) that ERPs are highly sensitive to the relevant processes, and that this sensitivity can be exploited to illuminate the cognitive and neurobiological underpinnings of sentence comprehension in native speakers and in language learners. In particular, we will demonstrate how the unique properties of ERPs permit novel tests of two fundamental tenets of modern-day psycholinguistics: the belief that syntactic processing always precedes semantic processing, and the belief that success at learning a language in adulthood is limited by an age-related decline in brain plasticity. The ERP evidence we describe here provides novel and perhaps unique perspectives on these widely held assumptions. Ultimately, however, all of the available methods (including ERPs) are imperfect tools. The most compelling conclusions often result from a convergence of evidence coming from very different methods.

## 14.2 SENTENCE COMPREHENSION IN A NATIVE LANGUAGE

Contemporary linguistic theories posit a number of distinct and largely independent levels of linguistic knowledge (Chomsky, 1986). A standard typology includes the levels of phonology, syntax, and semantics. The task of a linguist is to describe the units at each level and the rules that govern their combination. Psycholinguistic theories need to specify how closely this typology, which is based on linguistic observation and description, describes the cognitive and neurobiological events underlying the comprehension of a sentence. Critically, however, the psycholinguist's task does not end with the description of a simple typology but must extend to an account of how these different sources of knowledge are recruited in the service of comprehending a sentence. This includes, for example, specifying the order in which various sources of information are employed and the interactions (or lack of interactions) between them. The ultimate and most challenging step is to describe how these processes are implemented in the brain.

### *14.2.1 Syntax and Semantics*

Perhaps the most fundamental distinction is the one between sentence structure (syntax) and sentence meaning (semantics). To many linguists, sentences that violate syntactic constraints (such as *The cat will <u>ate</u> the food*) are clearly distinct from sentences that violate semantic constraints (such as *John buttered his bread with <u>socks</u>*). Whether this distinction characterizes accurately the processes underlying sentence comprehension has been a matter of debate. A standard assumption underlying much psycholinguistic work is that a relatively direct mapping exists between the levels of knowledge posited within linguistic theories and the cognitive and neural processes underlying comprehension (Bock & Kroch, 1989; Fodor, 1983; Forster, 1979). Distinct language-specific processes are thought to interpret a sentence at each level of analysis, and distinct representations are thought to result from these computations. However, other theorists, most notably those working in the neural net modeling domain, deny that this mapping exists (Elman, 1990; McClelland, St. John, & Taraban, 1989). Instead, the meaning of the sentence is claimed to be derived directly, without an intervening level of syntactic structure.

This debate is mirrored in the language dysfunction literature. The syndromes known as Broca's and Wernicke's aphasia were initially given motor and sensory interpretations, respectively. This approach gave way to linguistic descriptions in which each disorder was claimed to reflect the loss of a specific type of linguistic information or function (Caramazza & Zurif, 1976). Broca's aphasia was claimed to manifest (in addition to other impairments) an impairment in syntactic function. Wernicke's aphasia was associated with a degradation in the access to lexical semantics. These "linguistic" accounts of aphasia not only accepted the distinction between sentence form and meaning but also localized these aspects of language processing in different parts of the brain. Syntactic processes were claimed to be located in restricted parts of the left inferior frontal lobe, whereas semantic processes were claimed to be located in the posterior portion of the left temporal lobe. However, although this account has been quite influential, a closer inspection of the aphasic syndromes raises questions. The correlations between lesion site and the linguistically described aphasic symptoms turn out to be weak (Caplan, Hildebrandt, & Makris, 1996; Dronkers, 2000), and the aphasic symptoms tend to vary dramatically within a person over time (McNeil & Doyle, 2000). Such considerations have led some researchers to question the accuracy and utility of linguistically based accounts of aphasia (Bates & Dick, 2000; Blumstein & Milberg, 2000; McNeil & Doyle; Milberg & Blumstein, 2000).

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### 14.2.2 Neuroimaging and the Syntax/Semantics Distinction

Neuroimaging methods provide another means for identifying the types of processes used in sentence comprehension and mapping them onto the brain (Fiebach et al., chapter 17, this volume). For example, fMRI allows researchers to measure changes in blood flow (usually by recording changes in the blood oxygenation level dependent [BOLD] response; Jezzard, Matthews, & Smith, 2001) while neurologically intact subjects read or listen to tokens of the language. It is assumed that the BOLD response indirectly reflects neural activity. Although these methods represent major advances for the field of cognitive neuroscience, they are not without complications as tools for studying real-time language comprehension. First, the hemodynamic response to an event is delayed several seconds and evolves over 10 to 15 s. This temporal resolution contrasts starkly with the fact that in normal fluent conversation, speakers produce (on average) three words, four syllables, and 12 phonemes per sec (Levelt, 1999). Furthermore, the processing of a single linguistic unit, for example a word, most likely involves a constellation of processes, each having temporal durations of considerably less than 1 s. In other words, under conditions that approximate normal speaking and reading, it is very difficult to isolate the hemodynamic response to a particular word, much less the (phonological, syntactic, semantic, etc.) processing steps that occur in the processing of that word. In imaging experiments, all of these processes are represented in the time dimension by a single data point. Disentangling them (i.e., associating a specific process with a specific activated area) is not a trivial matter.

Second, because language comprehension is inherently an integrative process, one cannot reasonably assume that successive words and sentences are processed independently. This fact complicates efforts to isolate the response to particular words in a sentence by using event-related fMRI designs (e.g., Burock, Buckner, Woldorff, Rosen, & Dale, 1998). Event-related designs measure the BOLD response to rapidly sequenced individual events and assume that temporally overlapping BOLD responses summate linearly. Although the independence of overlapping hemodynamic functions has been demonstrated for simple visual stimuli (Dale and Buckner, 1997), the same cannot be assumed for words in sentences.

Third, even if the BOLD response to a particular word in a sentence could be isolated successfully, the BOLD response is maximally sensitive to sustained brain events and relatively insensitive to transient events (Savoy et al., 1995). Consequently, sustained brain events will always dominate the BOLD response and potentially obscure the transient language-related events of interest.[1]

These complications notwithstanding, fMRI has been used successfully to elucidate some aspects of word and sentence processing. The most fundamental and consistent finding has been that words and sentences activate the perisylvian areas of the left hemisphere that are classically associated with language dysfunction following brain damage (Bavelier, Corina, & Jezzard et al, 1997; Price, 1998). However, it is not unusual for areas in addition to these classical areas to show equally strong activation, and not all of the relevant perisylvian areas are always activated.

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The cross-experiment variability in fMRI results increases substantially when specific linguistic processes are examined. For example, studies attempting to localize semantic processing have reported activated areas including most of the left (and sometimes right) temporal lobe and various parts of the frontal lobe (Binder & Price, 2001). Attempts to localize syntactic processes have also varied widely, and have included the left inferior frontal cortex (Broca's area and surrounding cortex) and parietal and temporal regions, sometimes but not always lateralized to the left hemisphere.

Undoubtedly, some of this variation occurs due to differences in stimuli, task, and procedures. It is therefore instructive to examine results obtained in a relatively homogeneous set of studies that employ a common strategy for isolating a particular linguistic process. One seemingly straightforward stimulus manipulation contrasts the BOLD response to anomalies that involve different linguistic levels, for example, syntactic and semantic; the assumption is that the anomaly will engender more processing at the linguistic level of the anomaly, and that this processing will be reflected in a larger BOLD response in the affected areas of the brain. At least six neuroimaging studies employing this strategy have been published recently (Friederici, Ruschemeyer, Hahne, & Fiebach, 2003; Kang, Constable, Gore, & Avrutin, 1999; Kuperberg et al., 2000; Kuperberg, Holcomb, et al., 2003; Newman, Pancheva, Ozawa, Ozawa, Neville, & Ullman, 2001; Ni et al., 2000). Perhaps the most striking aspect of these collective results is the variability in outcome and conclusion (see Kuperberg, Holcomb, et al., for an excellent discussion of this point). For example, Kuperberg et al. (2000) conclude that the left and right temporal lobes are involved in semantic processing but do not identify any areas that are modulated specifically by syntactic anomalies. Ni et al. and Kang et al. conclude that the left inferior frontal lobe is involved in syntactic processing, whereas the posterior temporal lobes are more involved in semantic processing. Newman et al. (2001) conclude that superior frontal regions are involved in syntactic processing and inferior frontal and temporal regions are involved in semantic processing. In the two most recent studies, Kuperberg et al. (2003) conclude that overlapping networks (including inferior frontal and left temporal regions) are modulated in opposite directions by the two types of anomaly, with semantic anomalies evoking a larger BOLD response in this area and syntactic anomalies a weaker response, relative to a nonanomalous sentence condition. Friederici et al. (2003) conclude that syntactic anomalies evoke more activity in inferior frontal and anterior temporal regions in the left hemisphere, whereas semantic anomalies evoke activity bilaterally in the midtemporal regions.

There are a few notable consistencies across these studies. For example, the authors are in agreement (except Kuperberg, Holcomb, et al., 2003) that their syntactic and semantic manipulations identified distinct regions of the brain as being more involved in one level of analysis than the other. However, there is considerable disagreement about which brain regions are involved in syntactic and semantic processing. It is reasonable to speculate that this variance in outcome is due, in part, to the difficulty of isolating specific types of linguistic processes using fMRI when these processes are transient and closely sequenced in time.[2]

### *14.2.3ERPs and the Syntax/Semantics Distinction*

Unlike fMRI, ERPs have a temporal resolution exceeding that of the processes underlying language comprehension. ERPs are also maximally sensitive to transient events occurring in the brain and much less affected by sustained events. These advantageous properties allow one to hope that ERPs might be more successful at isolating individual processes as they occur in real time during sentence comprehension.

This hope has been fulfilled by two decades of accumulating evidence, much of it investigating the brain responses to syntactic and semantic anomalies. The crucial finding is that syntactic and semantic anomalies elicit qualitatively distinct ERP effects, and that these effects are characterized by distinct and consistent temporal properties. Semantic anomalies (e.g., *The cat will bake the food …* ) elicit a negative wave that peaks at about 400 ms after the anomalous word appears (the *N400 effect*; Figure 14.1A) (Kutas & Hillyard, 1980, 1984; Osterhout & Nicol, 1999). By contrast, syntactic anomalies (e.g., *The cat will eating the food …* ) elicit a large positive wave that onsets at about 500 ms after presentation of the anomalous word and persists for at least half a second (the *P600 effect*; Figure 14.1B) (Hagoort, Brown, & Groothusen, 1993; McKinnon & Osterhout, 1996; Osterhout, 1997; Osterhout & Holcomb, 1992, 1993; Osterhout, Holcomb, & Swinney, 1994; Osterhout & Mobley, 1995; Osterhout, McKinmon, Bersick, & Corey, 1996; Osterhout, McLaughlin, Allen, & Inoue, 2002; Osterhout & Nicol, 1999). In some studies, syntactic anomalies have also elicited a negativity over anterior regions of the scalp, with onsets ranging from 100 to 300 ms (Friederici, 1995; Neville, Nicol, Barss, Forster, & Garret, 1991; Osterhout & Holcomb, 1992; Osterhout & Mobley, 1995). These results are highly reproducible[3] and generalize well across types of anomaly (with anomalies involving phrase structure, agreement, verb subcategorization, and constituent-movement all eliciting P600-like effects), types of languages (including word-order languages such as English, Dutch, and French, and case-marked languages such as Italian and Japanese; Angrilli et al., 2002; Hagoort et al., 1993; Inoue & Osterhout, in preparation; Nakagome et al., 2001), and various methodological factors (including modality of the input, rate of word presentation, and presenting isolated sentences and natural prose; Allen, Badecker, & Osterhout, in press; McKinnon & Osterhout, 1996; Osterhout & Holcomb, 1993; Osterhout et al., 2002). These robust effects seem to indicate that the brain does in fact honor the distinction between the form and the meaning of a sentence.

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Furthermore, the available evidence suggests that the N400, but not the P600, is sensitive to a wide range of word properties, including word frequency, morphological content, and semantic relatedness. Conversely, the P600, but not the N400, is sensitive to the syntactic well-formedness of the sentence. A recent study by Allen,

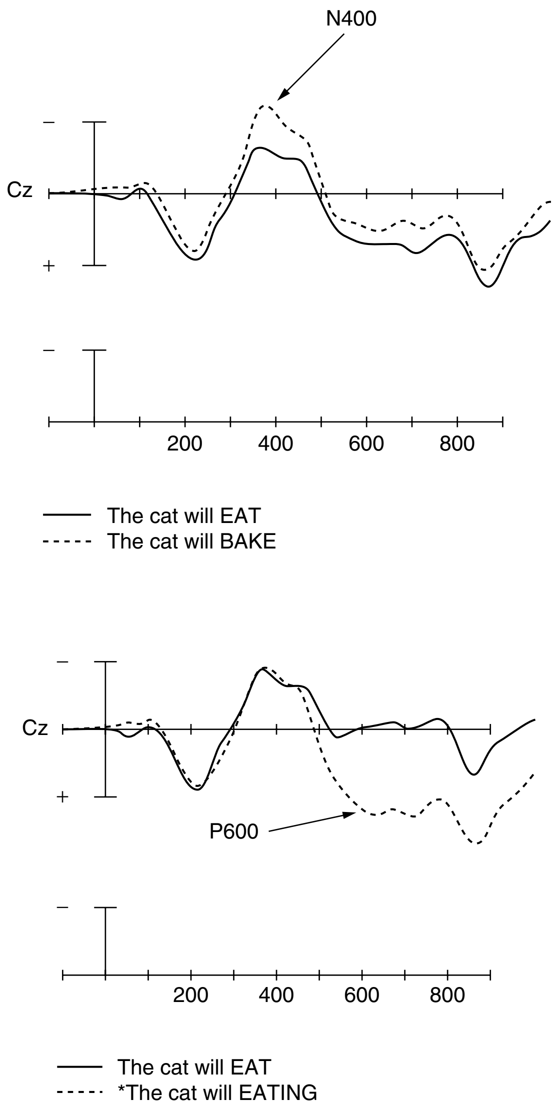


***Figure 14.1.*** (A) ERPs (recorded over the vertex) elicited by semantically anomalous words (dashed line) and nonanomalous control words (solid line) in sentences such as *The cat will* *eat/bake the food*. (B) ERPs elicited by syntactically anomalous (dashed line) and nonanomalous control words (solid line) in sentences such as *The cat will eat/eating the food*. Onset of the critical word is indicated by the vertical bar. Each hashmark represents 100 ms The vertical calibration bar represents 5 μV. Adapted from "On the distinctiveness, independence, and time course of the brain responses to syntactic and semantic anomalies," by L. Osterhout and J. Nicol, 1999, *Language and Cognitive Process, 14,* 283–317.

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et al. (in press) nicely illustrates this point. Allen et al. independently manipulated the normative frequency and syntactic well-formedness of verbs in sentences. These factors had independent effects: Word frequency affected N400 amplitude but not P600 amplitude, and syntactic well-formedness affected P600 amplitude but not N400 amplitude (Figure 14.2).

All of this ERP evidence converges on the conclusion that separable lexico-semantic and syntactic processes exist, and that manifestations of this distinction can be observed in scalp-recorded electrical brain activity. Furthermore, the ERP evidence shows quite clearly that the syntactic and semantic (or relevant correlated) processes are temporally distinct and transient events—and that ERPs, unlike fMRI, are capable of temporally isolating these (or correlated) processes as they occur in real time. That is, at a predictable moment in time during comprehension, the ERP waveform is sensitive specifically to lexico-semantic manipulations, whereas at another moment in time the waveform is sensitive specifically to syntactic manipulations.

Ideally, one would like to discern the neural sources of these language-sensitive ERP effects. By doing so, one might be able to isolate the processes of interest in both time and space. Unfortunately, the source of a given ERP effect (known as the "inverse solution") cannot be known with certainty. This follows from the fact that a large number of source configurations could produce an identical pattern of activity across the scalp (Nunez, 1995). Nonetheless, source estimates are possible, given certain limiting assumptions. The traditional approach to source localization has been to search for point dipole sources (Hämäläinen & Sarvas, 1989; Henderson, Butler, & Glass, 1975; Kavanaugh, Darcey, Lehmann, & Fender, 1978). In general, this entails assuming a small number of dipole sources and iterating through all possible combinations of dipole location, orientation, and strength, looking for the best match between the source model and the observed scalp distribution. This method brings with it numerous limitations and caveats (Halgren et al., 2002).

More recently developed alternative methods provide a true tomographic analysis analogous to that provided by neuroimaging methods. For example, Low Resolution Electromagnetic Tomography (LORETA; Pascual-Marqui, Michel, & Lehmann, 1994) estimates the current distribution throughout the entire three-dimensional brain. The primary assumption of this approach is that dramatic changes in current do not occur across contiguous areas of cortex (i.e., in adjacent voxels). The primary limitation is that the maximum spatial resolution is perhaps as low as 1 $cm^3$, significantly worse than fMRI or PET. The primary advantage, a crucial one, is that LORETA can provide an estimate of current distribution for each sample of brain activity (i.e., one estimate every few ms). Although LORETA should be viewed as a model or estimate rather than as an observation of current distribution, its reliability and validity have been established in some nonlinguistic domains (Anderer, Pascual-Marqui, Smlitsch, & Saletu, 1998; Pascual-Marqui, 1999; Pascual-Marqui, Esslen, Kochi, & Lehmann, 2002).

In our lab, we have been using LORETA to provide estimates of current distribution for the peaks of the N400 and P600 effects. In one study, we recorded ERPs from 20 native English speakers while they read sentences that were well-formed and coherent, or contained a syntactic or semantic anomaly. As expected, the syntactic and semantic anomalies elicited P600 and N400 effects, respectively. We then performed the LORETA analysis on the N400 peak (in both the semantically well-

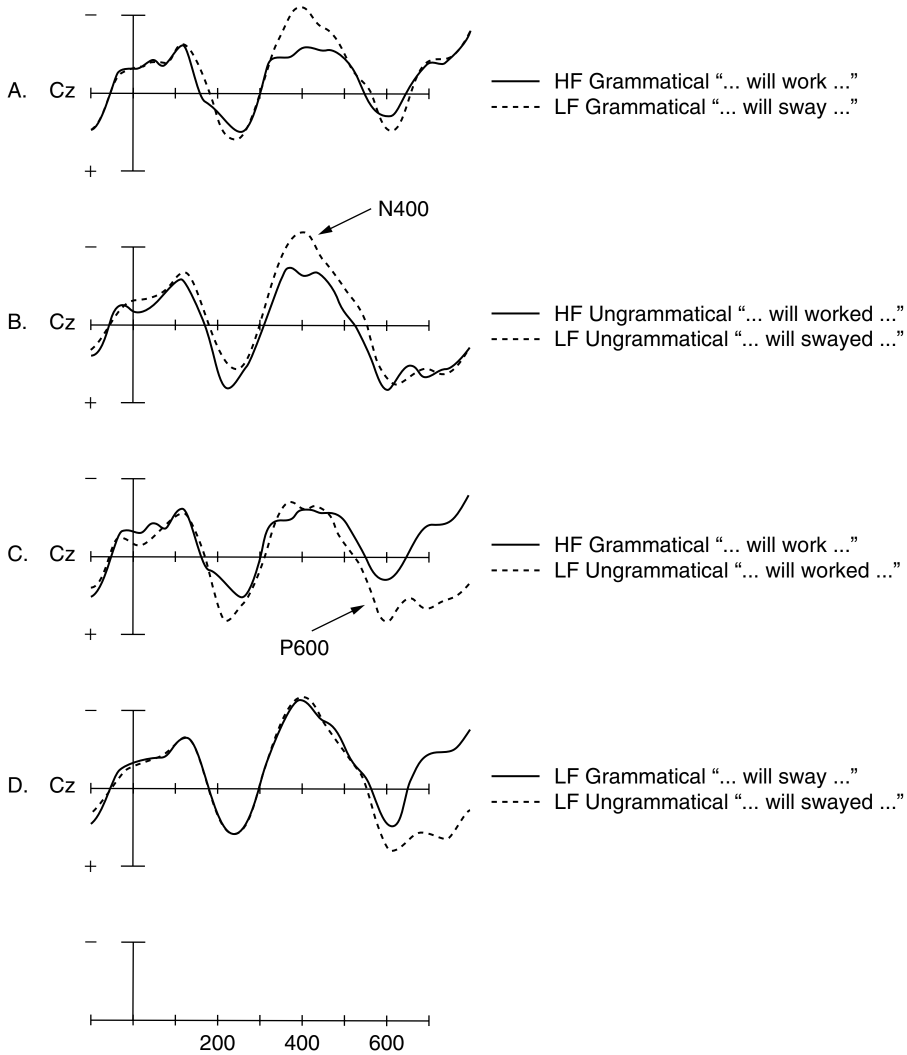


***Figure 14.2.*** (A) ERPs (recorded over the vertex) to high-frequency (solid line) and low-frequency (dashed line) verbs in grammatical sentences such as *The man will work/sway on the platform*. (B) ERPs to high-frequency (solid line) and low-frequency (dashed line) verbs in ungrammatical sentences such as *The man will worked/swayed on the platform.* (C) ERPs to grammatical (solid line) and ungrammatical (dashed line) high-frequency verbs. (D) ERPs to grammatical (solid line) and ungrammatical (dashed line) low-frequency verbs. Note that the effects of word frequency and grammaticality have independent effects on the ERP. Adapted from "Morphological analysis during sentence processing," by M. D. Allen, W. Badecker, and L. Osterhout, in press, *Language and Cognitive Process*.

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formed semantically anomalous conditions) and on the P600 midpoint in the syntactically anomalous condition, and on the corresponding sample in the syntactically well-formed condition.[4]

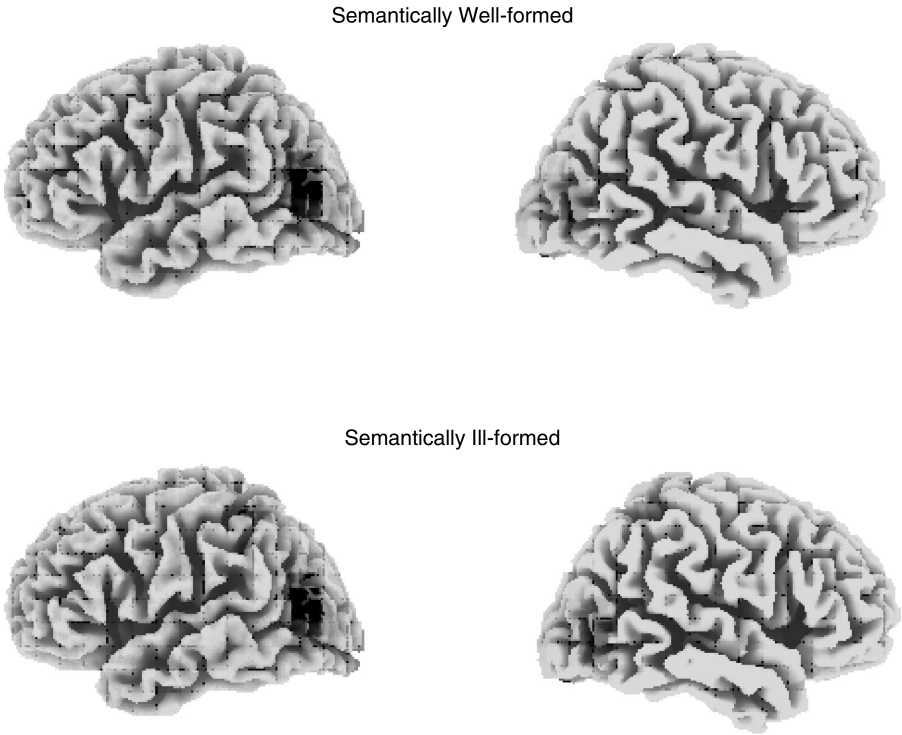


***Figure 14.3.*** LORETA solutions for N400 peak (at 410 ms) elicited by critical words in the well-formed (top panel) and semantically anomalous (bottom panel) condition. See text for more detail.

The results of the LORETA analysis were striking. In the semantic condition (Figure 14.3), the estimated current distribution for the N400 peak (at 410 ms) was largest in the posterior middle temporal lobe and angular gyrus of the left hemisphere [Brodmann's area (BA) 39]. This was true for both the well-formed and semantically anomalous conditions, although the current distribution in this area had greater intensity in the anomalous condition. In the syntactic condition (Figure 14.4), the primary source of current for the P600 midpoint (at 603 ms) was in the left inferior frontal cortex (BA 44, 45, and 47). When the stimulus was syntactically anomalous, the current spread throughout the left prefrontal cortex and into the left anterior temporal lobe.

Our LORETA results are striking because they are highly consistent with the classic lesion-based model of language and brain. The putative source of the N400 component, which is sensitive to properties of words and to meaning relations between words, is located in the part of the brain that, when damaged, produces the most problems with words and meaning (e.g., Dronkers, 2000). The putative source of the P600 effect (and the same time point in the syntactically well-formed condition) is localized to the left inferior frontal cortex, which is classically associated with agrammatism, and to the left anterior temporal cortex, which is the area most

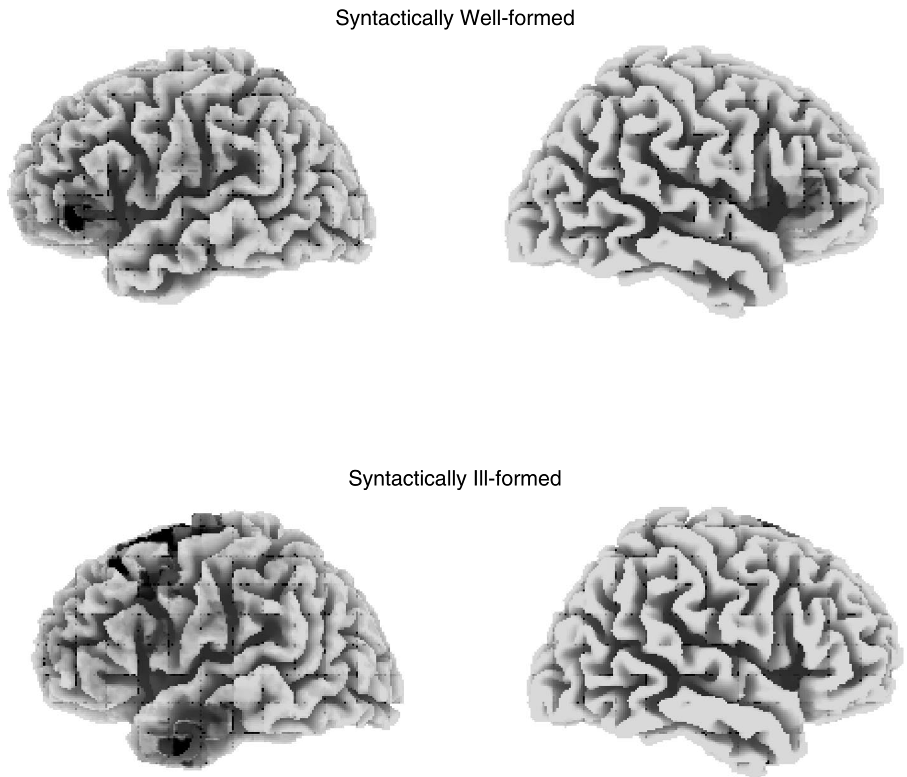


***Figure 14.4.*** LORETA solutions for the P600 midpoint (at 603 ms) elicited by critical words in the well-formed (top panel) and syntactically anomalous (bottom panel) conditions.

commonly damaged in cases of agrammatism (Dronkers). These results are also consistent to a degree with fMRI results. The posterior temporal lobe/angular gyrus region of the left hemisphere (and in particular BA 39) is one of the few regions that is almost always activated in studies attempting to isolate semantic processing (Price, 1998). The inferior frontal lobe of the left hemisphere is frequently activated in studies attempting to isolate syntactic processing (Caplan et al., 1996).[5]

AU: Citation in Note 5: Dale et al. (2002)The year is 2000 in ref. list.

One important caveat is that although the stimulus manipulations affecting the N400 and P600 are well understood, the specific cognitive processes underlying them are not. These effects might be direct manifestations of the syntactic and semantic processes or they might be manifestations of processes that are correlated with, but indeterminately removed from, the linguistic process themselves. Deciding which of these possibilities is correct might turn out to be an intractable problem, as impossible as altering the temporal properties of the brain's hemodynamic response or discovering perfect correlations between a lesion site and deficit patterns. However, what seems to be intractable might become less so given data from other methods of investigation. For example, given both the LORETA estimates of the current distribution for the N400 and P600 effects *and* the lesion data, one could rationally argue that these effects do in fact index specifically semantic and syntactic processing. Similarly, given both the highly variable semantic-processing fMRI results *and* the lesion and ERP results, compelling claims can be made concerning the regions in the brain most implicated in semantic processing. Although an appreciation for the value of converging evidence is an old and perhaps out-of-fashion virtue, its value has only increased with the advent of these new, but imperfect, investigative methods.

### *14.2.4 Coordination Between Syntax and Semantics in Sentence Processing*

Because of their unique constellation of properties, ERPs can also be used to address longstanding issues concerning the coordination of syntactic and semantic processing. Theory regarding this issue has been deeply influenced by a family of syntax-first models of linguistic structure (Chomsky, 1981) and language processing (Ferreira & Clifton, 1986; Fodor & Ferreira, 1998). The psycholinguistic models posit that language comprehension is controlled by an initial stage of purely syntactic processing. As words arrive in the linguistic input, they are rapidly organized into a structural analysis by a process that is not influenced by detailed lexical or semantic knowledge. The output of this syntactic process then guides semantic interpretation. Syntax-first processing has been implicated in accounts of garden-path phenomena, in which readers and listeners initially misanalyze sentences containing temporary syntactic ambiguities. Consider, for example, sentences (1a) and (1b):

(1) a. *The doctor believed the patient was lying.*
    b. *The doctor believed the patient after hearing the story.*

Readers of sentences like (1a) often initially interpret the second noun phrase (*the patient*) as the direct object of the first verb (*believed*), when it is actually the subject of an embedded clause (*the patient was lying*). Misanalysis is detected in the form of processing difficulty when readers encounter *was*, which is only consistent with the correct analysis. This processing difficulty is manifested in eye-fixation times, regressive eye movements, and P600 effects in the ERP (Ferreira & Clifton, 1986; Osterhout & Holcomb, 1992). Syntax-first models have claimed that, due to the control of initial interpretative commitments by exclusively syntactic mechanisms, garden-path errors occur even in the presence of potentially disambiguating semantic information (e.g., Ferreira & Clifton). In situations of temporary syntactic ambiguity such as (1a, b), processing is controlled by a bias to choose the simplest grammatically licensed structural analysis [in (1a, b), the direct object analysis]. Whenever the simplest structural analysis is not the correct analysis, garden-path effects are predicted.

While garden-path effects have been widely observed, other studies have shown that they can be mitigated or eliminated by some types of nonsyntactic information. For instance, Garnsey, Pearlmutter, Myers, & Lotocky, (1997) found that semantic plausibility affected the likelihood of garden-path effects. Sentences in which the direct-object interpretation is implausible (e.g., *The doctor believed the medication would work*) result in small or nonexistent garden-path effects. Other studies have shown effects of a wide range of constraints, including detailed lexico-syntactic knowledge, semantics, and discourse knowledge (cf. MacDonald, Pearlmutter, & Seidenberg, 1994; Trueswell & Tanenhaus, 1994). The influence of such factors on ambiguity resolution seems inconsistent with the syntax-first prediction that initial processing commitments are not influenced by nonsyntactic knowledge.

To account for these interacting influences of syntactic and nonsyntactic information on sentence processing, theorists have developed a diverse family of constraint-based models. These models posit a probabilistic constraint-satisfaction process in which syntactic knowledge is only one of a number of constraints on interpretation. Syntax-first models have not, however, been completely invalidated by demonstrations of rapid interactivity. The most recent proposals continue to posit an initial stage of purely syntactic processing, albeit one with a short duration (Frazier & Clifton, 1996). According to these proposals, a rapid influence of nonsyntactic knowledge on sentence parsing can be explained in terms of re-analysis. For example, if processing difficulty at *was* in (1a) is eased by semantic knowledge, this might mean that a direct-object analysis was initially pursued but rapidly revised using information about plausibility.

Thus, a consensus has emerged concerning the rapid nature of interaction between syntactic and semantic knowledge, without resolving fundamental disagreements about the degree to which syntactic processing controls other aspects of language processing. These theoretical developments have brought the field against some limitations of the standard garden-path paradigm. Garden-path experiments examine the impact of nonsyntactic information exclusively in situations where syntactic cues are indeterminate. The question is usually whether or not syntactic processing is influenced by some nonsyntactic form of knowledge (or whether it is independent).

However, the implicit assumption in all of this work (regardless of theoretical bias) is that unless syntactic cues are indeterminate, syntax always controls the direction of processing. We describe here a recent study in our laboratory (Kim, Relkin, Lee, & Hirsc, in preparation) that examined semantic influences on sentence comprehension in syntactically *unambiguous* situations. The goal of the study was to test the widespread assumption that, in the absence of syntactic uncertainty, syntactic information is "in charge" of sentence processing or, more specifically, that semantic processing is always fundamentally dependent on the output of the syntactic processing system. Kim et al. recorded ERPs while participants read strings containing linguistic violations, as in (2a), and well-formed controls like (2b) and (2c):

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(2) a. *The mysterious crime had been <u>solving</u> the detective. (verb violation)*
b. *The mysterious crime had been <u>solved</u> by the detective. (passive control)*
c. *The brilliant detective had been <u>solving</u> mysterious crimes for decades. (active control)*

In (2a), the first noun phrase *mysterious crime* is highly plausible as the logical object (theme) of the verb *solve* but anomalous as the logical subject (agent). The syntactic cues in the sentence conflict directly with these semantic properties. The

-*ing* inflection of the verb is consistent with the anomalous agent interpretation but not the theme interpretation [as opposed to -*ed* as in (2b)]. Sentence (2a) provides a special situation—contrasted with the well-formed (2b) and (2c)—in which syntactic and semantic constraints point toward directly opposed functional outcomes. The interaction of syntactic and semantic processing in such situations can be studied with ERPs. If syntactic processing controls semantic processing, then an agent interpretation of the first noun phrase should be pursued. The implausibility of this interpretation should elicit an enhanced N400 component for violation verbs (2a) relative to control verbs (2b) and (2c). By contrast, semantic processing may operate with some independence from syntactic control such that the plausible theme interpretation of the noun phrase is pursued, even though it directly conflicts with syntactic cues in the string. Because this interpretation is in direct conflict with the syntactic cues in the string, it is possible that readers will encounter *syntactic* processing difficulty at the verb. That is, powerful semantic cues may cause a well-formed string to appear ill-formed. Such a perceived syntactic incongruity might elicit a P600 effect. Note that the two different functional outcomes mentioned above cannot be distinguished by reading time or eyetracking measures, which conflate syntactic and semantic processing difficulty at the anomalous verb.

ERPs to the verbs in each sentence type are shown in Figure 14.5. Violation verbs elicited a robust P600 effect compared to the control conditions, but no increase in N400 amplitude. These results seem to indicate that syntactic processing difficulty occurred at the verb when its inflection conflicted with available semantic cues. At the same time, there is no indication that semantic processing is guided by syntactic cues into the difficult logical-subject interpretation.[6,7]

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The idea that syntactic processing precedes and drives semantic interpretation is pervasive in psycholinguistics. Our results clearly do not fit well with that idea. Instead, it appears that at least under some circumstances, semantic processing exhibits a degree of independence from syntactic control and in fact seems to operate in advance of, and drive, syntactic processing. An important theoretical issue raised by this and related work (see Kolk, Chwilla, van Herten, & Oor, 2003; Kuperberg, Sitnikova, Caplan, & Holcomb, 2003) is the notion of processing independence. With respect to the claims of syntax-first models, the Kim et al. results indicate that the independence of semantic processing is greater than predicted and that the independence of syntactic processing is less than predicted.

We suggest that syntactic and semantic processing are indeed separated by a form of independence, but a weak form. The independence of these processes enables them to pursue an internally attractive analysis *even when it is inconsistent with the output of other processes*. Furthermore, rather than operating in a serial fashion (as proposed by the two-stage garden-path theory), syntactic and semantic processing operate in parallel. Finally, it seems likely that these processes undergo a near-constant interaction. Thus, syntactic processing might guide semantic processing in *John was disliked by Mary*, where syntactic information points to the proper thematic role assignments (i.e., the passive morphology indicates that *John* is the theme and not the agent of *dislike*). Semantic processing might guide syntactic processing in *We gave <u>John</u> the money*, where semantic knowledge supports the proper syntactic

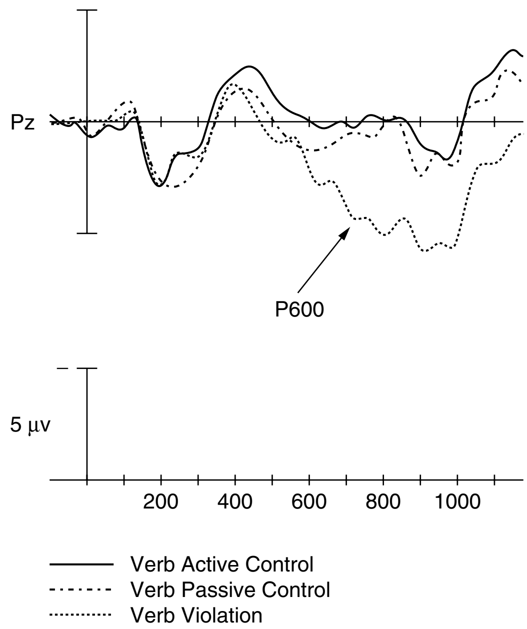


***Figure 14.5.*** ERPs (recorded over the posterior site PZ) elicited by critical words in the two nonanomalous control conditions and in the anomalous verb violation condition (small dashes).14x05.eps

analysis (indirect vs. direct object) of *John* (i.e., *John* would make an excellent recipient and an unlikely theme for the verb *give*).

These considerations suggest a potentially rich area of investigation concerning the nature of syntactic and semantic processing. We know that in *The mysterious crime had been solving*, the verb *solving* elicits a P600 effect and not an N400 effect. Presumably, this happens because the syntactic analyzer tries to find an analysis consistent with a "Predicate = *solve,* Theme = *crime*" interpretation. But we also know that in *The cats will bake the food*, the verb *bake* elicits an N400 effect and not a P600 effect (Osterhout & Nicol, 1999, and discussed in the "Syntax and Semantics" section, this chapter). It appears that the implausibility of cats acting as agents in this scenario does not cause the syntactic analyzer to flail away trying to come up with an alternative structure; instead, an implausible but syntactically supported interpretation is pursued, with difficulty.

The above observations raise a compelling paradox. *The crime had been solving* and *The cats will bake* are quite similar; in each scenario, the subject is an implausible Agent for the verb. Why, then, do the verbs in these two sentences elicit such different brain responses? Two hypotheses come to mind. Perhaps the critical factor is that a strong "semantic attraction" exists between the verb *solve* and the theme *crime*, whereas no such attraction exists between the verb *bake* and *cat*. Alternatively, the critical factor might be that the syntax of *The mysterious crime had been solving* can be easily "fixed" to support a semantically plausible interpretation (simply changing the verb's inflection from *-ing* to *-ed*), whereas no such easy fix is available in the sentence *The cats will bake the food*. These two hypotheses can be contrasted by examining sentences containing a strong semantic attraction, one that is inconsistent with the syntax and that cannot be made to fit the syntax with an easy syntactic fix. For example, the sentence fragment *The meal began to devour* does not allow an easy fix of the syntax to conform to a "theme = *meal*" interpretation, but the system might try to find one anyway due to the semantic attraction between the verb *devour* and the theme *meal*. If so, then *devour* should elicit a P600 effect, rather than an N400 effect. Exactly this type of result has been reported in two recent studies (Kolk et al., 2003; Kuperberg, Sitnikova, et al., 2003). Kuperberg, Sitnikova, et al. report that the verb *eat* in the sentence *For breakfast, the eggs began to eat* elicits a P600 effect, rather than an N400 effect. Apparently, strong semantic attractions between predicates and arguments induce the syntactic analyzer to work overtime, searching for a structure that is consistent with the attraction. To phrase it differently: The system commits itself to the semantic attraction (hence the lack of an N400 effect) and insists on trying to "fix" the syntax (hence the presence of a P600 effect).

Obviously, more work is needed to test the plausibility of this model and to more completely understand how and when syntactic and semantic processing influence each other. What is already clear, however, is that ERPs are useful tools for investigating complex issues in sentence comprehension that have been difficult to study using other methods.

## 14.3 WORD AND SENTENCE PROCESSING IN SECOND-LANGUAGE LEARNERS

One of the standard tenets of modern-day psycholinguistics is that the ability to learn a new language degrades with age. Age-related decreases in language-learning ability have been reported for most aspects of language (including phonemes, words, and grammar), and adults are often claimed to achieve lower levels of second-language proficiency than children. Although the causes of these age effects on proficiency are controversial, two frequently cited theoretical explanations stand out. One explanation involves the putative existence of a critical period for second-language learning. According to this explanation, language learning is constrained by maturational factors (specifically, brain maturation) that circumscribe a critical period (which, according to most accounts, ends around puberty) for native-like attainment. Behavioral studies appear to confirm this notion by showing that the proficiency scores of L2 learners on a variety of language tasks decline with the age of initial exposure to the second language (Johnson, 1992; Johnson & Newport, 1989).

Another explanation attributes the age-related declines in L2 learning to the effects of increasing experience with a first language. Neural network simulations provide a convenient framework for understanding effects of L1 learning on L2 learning. In these simulations, early learning results in the entrenchment of optimal network patterns, after which new learning requires considerable training. Consistent with this view, it has been demonstrated that early experience with phonemes (Kuhl,

2000) and words (Ellis & Lambon Ralph, 2000) seems to degrade the ability to learn new phonemes and words later in life.

Although on the surface these two explanations appear to be quite distinct, they both implicate the same underlying cause for the age-of-acquisition effects on L2 learning, namely, a reduction in neural plasticity that degrades the ability to learn new linguistic information. However, despite a considerable consensus about the accuracy of this claim, there is little direct evidence to support it. The ideal method for investigating the plasticity hypothesis would provide direct measurements of brain responses to L2 words and sentences. This would permit researchers to evaluate changes in brain activity that occur over time as a person attempts to acquire a new language.

Recently, several studies using neuroimaging methods (i.e., PET, MRI) have investigated the reduction "in plasticity" hypothesis by contrasting groups of L2 speakers who acquired the L2 at different ages. A result indicating that, for example, prepubescent learners represent their L1 and L2 similarly, whereas postpubescent learners do not, would be consistent with the critical-period hypothesis. Exactly that type of evidence was reported in one recent study (Kim et al., 1997). Early L2 learners showed highly similar patterns of activation for their L1 and L2, whereas late learners showed differences, most notably in Broca's area (for other studies showing L1/L2 differences see Dehaene et al., 1997; Halsband, Krause, Sipila, Teras, & Laihinen, 2002; Perani et al., 1996; Waterburger et al., 2003). However, other studies have reported no significant effects of age of acquisition (Chee, Caplon et al., 1999a; Chee, Tan et al., 1999b; Hasegawa, Capenter, & Just, 2002; Hernandez, Martinez, & Kohnert, 2000; Illes et al., 1999; Klein, Milner, Zatorre, Zhao, & Nikelski, 1999).

One partial explanation for the inconsistent results implicates the almost universal use of cross-sectional, between-subject designs in prior fMRI (and ERP) work on L2 learning. This design makes it very difficult to properly control numerous subject variables (e.g., L2 fluency and the quantity and quality of L2 experience) that could easily confound the age effects (Chee et al., 2001; Perani et al., 1998). The best way of avoiding such pitfalls is to longitudinally study a group of novice learners as they become increasingly proficient in the L2. A longitudinal design allows one to examine changes in brain activity and behavior relative to responses observed during an initial state of near-total incompetence in the L2 within the same group of learners. By including a group of subjects with native proficiency, one can compare intermediate states of language competence to both the beginning (no competence) and end (native competence) states of language learning. And by confining the study to learners who have had qualitatively and quantitatively similar exposure to the language, one avoids the problems of interpretation introduced by variable linguistic experiences across subject groups. However, even under ideal circumstances, uncertainties often exist (for reasons discussed above) concerning the relationship between the BOLD signal and the transient events underlying language comprehension.

In principle, ERPs provide the temporal resolution and sensitivity needed to reveal how (and potentially where) the L2 is processed, how similar this processing is to L1 processing, and how L2 processing changes as a function of increasing L2

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experience. In a series of ERP experiments, we have tracked changes in brain activity that are correlated with increasing exposure to the L2 in adult L2 learners. We describe here two experiments, one involving L2 word learning (McLaughlin, Osterhout, & Kim, in preparation), and a second involving sentences (Osterhout et al., in preparation). In both studies, English-speaking novice French learners were studied longitudinally as they progressed through their first year of classroom French instruction. Learners were tested three times: near the beginning, in the middle, and near the end of the instructional period. This design allowed us to track changes in brain activity within a single group of language learners, and ensured that the learners were relatively homogeneous in their initial lack of L2 proficiency and in their subsequent L2 experience.

McLaughlin et al. examined word learning by measuring learning-related changes in N400 amplitude, which is sensitive to both lexical status (i.e., whether or not a letter string is a word) and word meaning (Bentin, 1987; Kutas & Hillyard, 1980). For native speakers, N400 amplitude is largest for pronounceable, orthographically legal nonwords (pseudowords, e.g., *flirth*), intermediate for words preceded by a semantically unrelated context, and smallest for words preceded by a semantically related context. Our goal was to determine how much L2 exposure is needed before the language-learners' brain activity elicited by L2 words and word-like stimuli resembles that of a native speaker.

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McLaughlin et al. asked adult French learners to make word/nonword judgments to a sequence of French words and pronounceable nonwords. They found that after only 14 hr (roughly two weeks) of L2 instruction, the nonwords elicited a robustly larger-amplitude N400 than did words (Figure 14.6). This was true even though learners showed random behavior (d-prime = 0) when making explicit word/nonword judgments about these stimuli. Furthermore, the correlation between hours of instruction and the word/nonword N400 difference was very robust ($r$ = .74), suggesting that the N400 difference was approximately a linear function of the amount of L2 exposure. Effects of word meaning, manifested as smaller-amplitude N400s to words preceded by related than by unrelated words, were observed after approximately 62 hr of instruction. By the end of the instructional period (after approximately 138 hr), the amplitude of the word/nonword differences approximated that typically observed in native speakers, even though learners' conscious lexicality judgments remained very poor (d-prime < 1). Importantly, no N400 differences were observed for a group of subjects who had received no French instruction.

Thus, even for adult learners, the brain response to L2 words and word-like nonwords changes dramatically with very little L2 exposure. Furthermore, these changes are not random, but instead, almost immediately begin to approximate the responses seen in native speakers to analogous stimuli, and occur even while the learner behaves randomly when making consciously lexicality judgments to these stimuli. These results seem to indicate that the brain response to words and word-like strings in the L2 changes dramatically with remarkably little L2 exposure.

A second experiment was motivated by the observation, discussed above, that syntactic and semantic anomalies embedded within sentences elicit distinct ERP effects (the P600 and N400 effects, respectively). With respect to adult L2 learning, several questions immediately come to mind: How much experience with a language

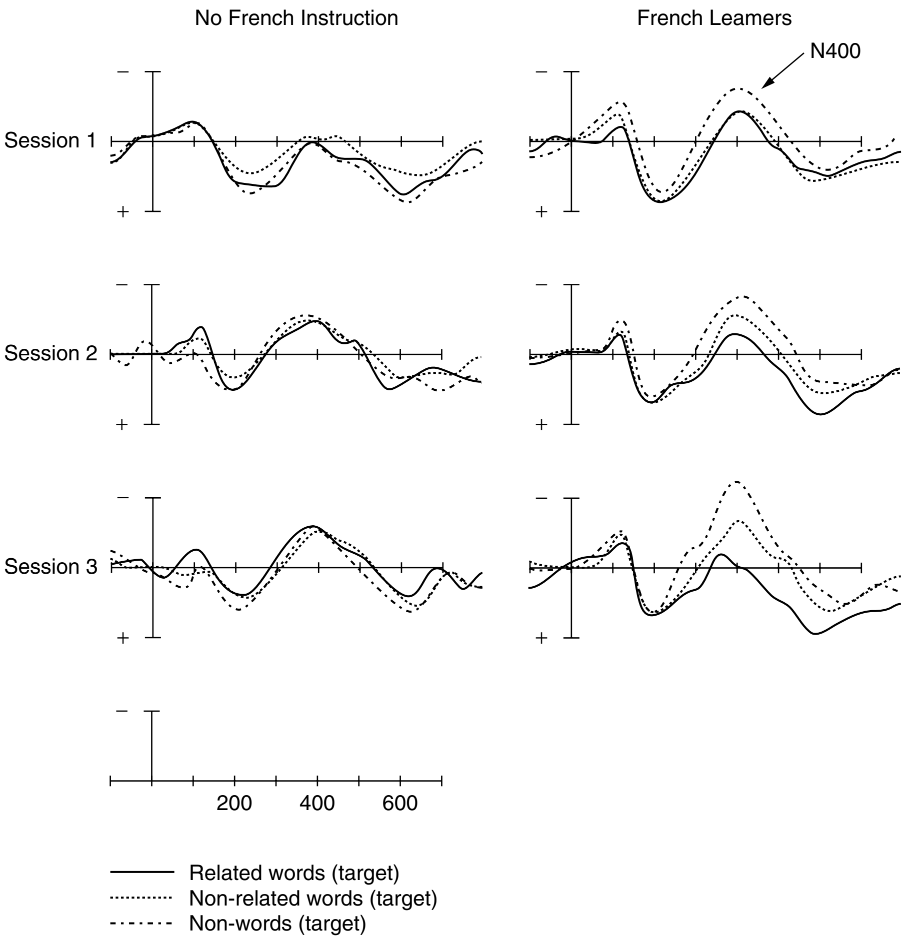


***Figure 14.6.*** ERPs (recorded over the vertex) for No Instruction (left panel) and French Instruction (right panel) subjects, recorded at the three successive testing sessions. ERPs are plotted for three types of target strings: target words that were semantically related to the prime word (solid line), target words that were not semantically related to the prime word (small dashes), and target nonwords (large dashes).

is needed for the learner's brain to distinguish between well-formed and ill-formed sentences? How much experience is needed for the learner's brain to distinguish between different types of linguistic anomalies (e.g., syntactic and semantic)? And how much experience is needed for the learner's brain to respond to these anomalies like the brain of a native speaker of the L2? To answer these questions, we presented well-formed French sentences and French sentences containing either a semantic or a syntactic anomaly, as in the below examples:

(3) *Sept plus <u>cinq*livre</u> font douze*. (semantic condition)
(4) *Tu <u>adores*adorez</u> le francais*. (verb conjunction condition)

(5) *Tu manges des hamburgers*hamburger pour diner.* (article–noun agreement condition)

In (3), the noun *livre* is semantically anomalous. In (4), the verb *adorez* is conjugated incorrectly, given the preceding sentence fragment. In (5), the noun *hamburger* disagrees with the syntactic number of the plural article. Thus, the anomalous version of (3) is semantically anomalous, whereas the anomalous versions of (4) and (5) are syntactically anomalous. Importantly, the two syntactic rules differ in terms of their relative prevalence in the L1 and L2. Verb conjugation in French is quite similar to that in English; however, article–noun agreement is exceedingly common in French but is much less so in English.

Subjects were native French speakers and a group of novice, adult French learners. Learners were tested after approximately 1 month, 4 months, and 8 months of French instruction. As expected, native French speakers showed an N400 effect to the semantically anomalous words, and very large P600 effects to the two types of syntactic anomalies. The French learners, as is often the case, showed striking individual differences, both in a behavioral "sentence acceptability judgment" task and in the pattern of ERPs elicited by the anomalous stimuli. We then segregated the learners into upper ("fast learners") and lower ("slow learners") halves, based on their performance on the sentence-acceptability judgment task, and averaged the ERPs separately for each group. Results for the "fast learner" group will be discussed here. At each testing session, including the initial session that occurred after just 1 month of instruction, semantically anomalous words elicited a robust N400 effect, and this effect changed minimally with increasing instruction (Figure 14.7). The finding of real interest pertained to the two syntactic conditions. We will describe the verb conjugation condition first (Figure 14.8). After just 1 month of instruction, the learners' brains discriminated between the syntactically well-formed and ill-formed sentences. However, rather than eliciting the P600 effect (as we saw in native French speakers), the syntactically anomalous words elicited an N400-like effect. By 4 months, the N400 effect had largely disappeared and was replaced by a P600-like positivity. By 8 months, this P600 effect increased in amplitude and the N400 effect was entirely absent.

One interpretation of these results is that the learners initially learned about words but not rules. That is, after one month of French instruction they recognized, for example, that the word *adorez* does not fit well in the context "Tu … " but had yet to grammaticalize this knowledge (and hence elicited an N400 effect). With a bit more exposure, this knowledge became codified as a syntactic rule (and hence elicited a P600 effect). Regardless of the validity of this speculation, this experiment, much like the McLaughlin et al. experiment, demonstrates the dramatic changes in the brain responses to tokens of the L2 that occur with very little L2 exposure. As in the McLaughlin et al. study, less than a year of L2 exposure was sufficient to produce brain responses that were qualitatively similar to native-speaker brain responses.[8]

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These findings seem to argue in favor of a great deal of brain plasticity, even with minimal adult L2 instruction. However, the results in the article–noun agreement condition clearly demonstrated limits to this plasticity: Learners' judgments concerning the grammaticality of these sentences were uniformly poor (even after

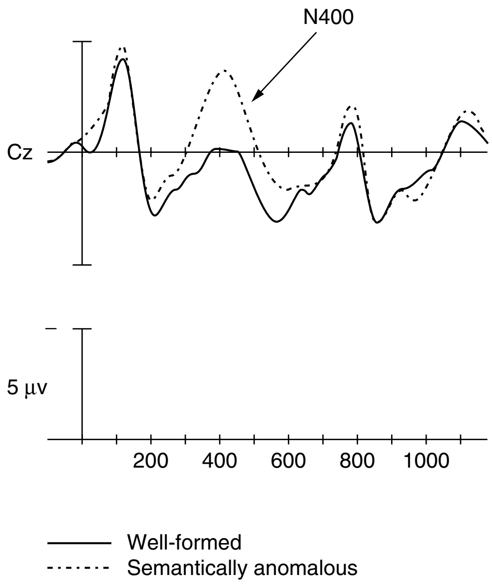


***Figure 14.7.*** ERPs (recorded over the vertex) to critical words in the well-formed (solid line) and semantically anomalous (dashed line) conditions, collapsed over the three testing sessions.

a year of L2 instruction), and no differences were observed in the ERPs to critical words in the grammatical and ungrammatical sentences (Figure 14.9). This was true even though article–noun number agreement is seemingly a simple rule, and even though both rules were encountered at roughly the same (early) point in the instructional period. Informal discussions with the French instructors indicated that learners often have more trouble learning the agreement rule than the conjugation rule. Although the proper interpretation of this set of results is uncertain at the moment, one possibility is that the rate of L2 learning is determined in part by L1–L2 similarity. Those aspects of the L2 that are highly similar to the L1 will be learned very rapidly; those aspects that are sufficiently dissimilar will be learned very slowly. Dissimilarities might include the presence of a rule in one language and its absence in the other language, differences in how the rule is expressed across languages, or differences in the prevalence or salience of that rule across languages. This proposal is not new, as influences of L1–L2 similarity on L2 learning have been documented for many years (Gass & Selinker, 1992; Odlin, 1989, Ringbom, 1987).

In summary, these findings seem to demonstrate that dramatic changes in brain activity occur during the earliest stages of adult L2 learning. Furthermore, these changes are sometimes, but not always, accompanied by increasing accuracy in related behavioral judgments. Finally, the qualitative nature of these changes might reveal important details of what has been learned. Importantly, however, mere exposure to the L2 is not enough to guarantee increasing sensitivity to every aspect of the language; these rapid changes in brain activity might depend on similarities across the learner's L1 and L2.

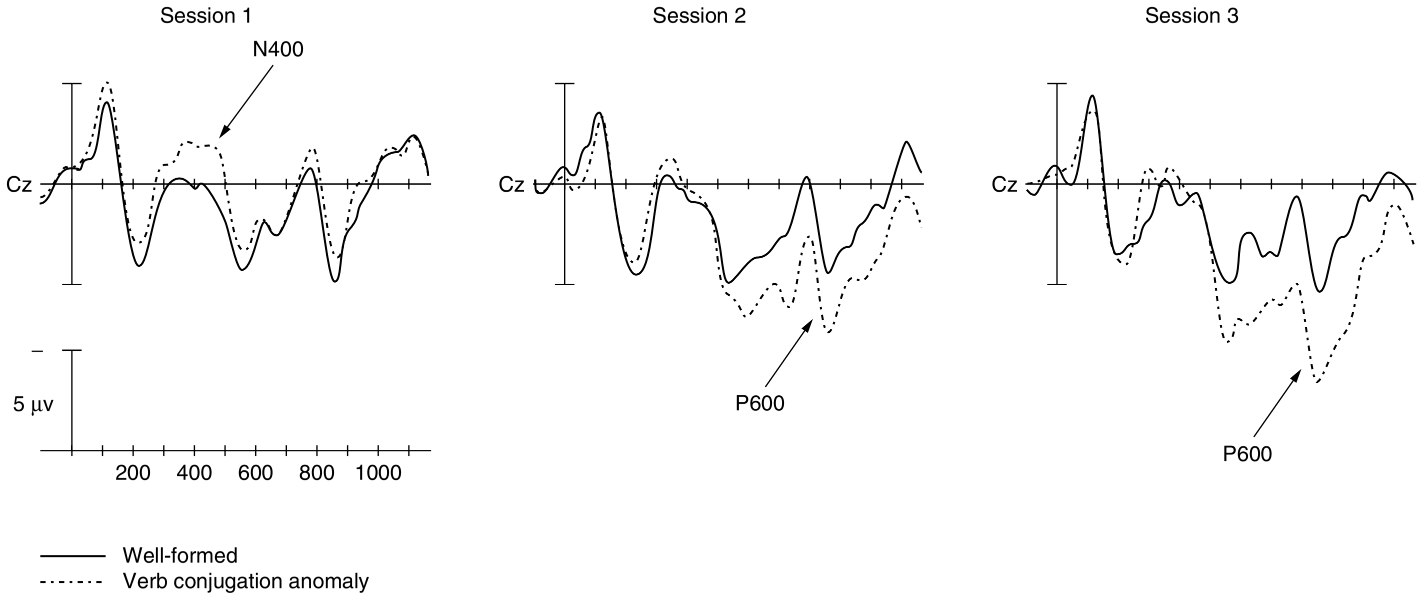


***Figure 14.8.*** ERPs (recorded over the vertex) to critical words in the well-formed (solid line) and verb conjugation anomaly (dashed line) conditions, plotted separately for each of the three testing sessions.

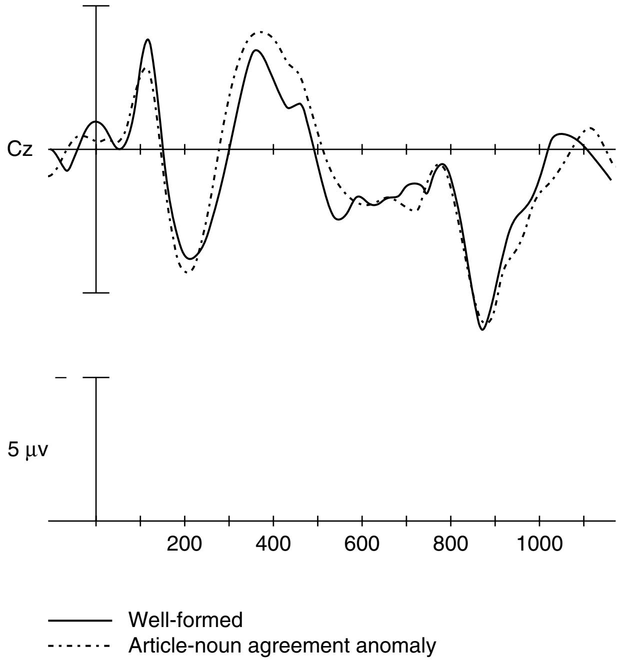


***Figure 14.9.*** ERPs (recorded over the vertex) to critical words in the well-formed (solid line) and article–noun agreement anomaly (dashed lines) conditions, collapsing over the three testing sessions.

## 14.4 CAVEATS AND CAUTIONS

As is the case with any method, ERPs have their limitations. The most fundamental limitation is one we noted earlier in this chapter: It is relatively easy to identify the stimulus manipulations (that is, the antecedent conditions) that produce or modulate some ERP effect, but it is often very difficult to identify the precise cognitive events underlying the effect.[9] Misattributing a particular function to a particular ERP effect can have serious consequences, particularly with respect to developing and testing theories of language processing. To illustrate this point, we will discuss two example cases in which particular ERP effects have been tied to specific cognitive processes. In both examples, we present evidence that at the very least raises some questions about the general veracity of these claims. The goal of this exercise is to demonstrate the difficulty of ascertaining with any confidence the precise process made manifest by some ERP effect. We are not claiming that these claims are universally wrong, nor are we disparaging the science that motivates them.

The first example concerns the distinction between content (or “open-class”) and function (or “closed-class”) words (see Hoen and Dominey, chapter 16, this volume). Content words (nouns, verbs, adjectives, etc.) play a largely referential role in language, whereas function words (articles, prepositions, auxiliary verbs, etc.) play a primarily syntactic role. Neville and colleagues (e.g., Neville, Mills, &

Lawson, 1992) have argued that content words elicit a negative-going wave that peaks at about 400 ms (N400), whereas function words elicit a negativity that peaks at about 280 ms (N280). The N400 component is largest over the posterior parts of the scalp, whereas the N280 is largest over anterior portions of the left hemisphere. These areas of maximum amplitude are interesting because they correspond to the lesion sites that putatively produce problems in processing the meaning and form of sentences, respectively. Such evidence has led Neville and colleagues to conclude that the N400 and N280 reflect specifically the semantic and syntactic functions of these two word classes, respectively.

The problem with this claim is that many variables are confounded with the content/function distinction. Most notable in this regard is the confounding between word class, on the one hand, and word length and normative word frequency, on the other. Function words tend to be shorter and more frequent than content words. It could be, then, that the ERP differences between content and function words are due mostly to the physical properties of length and frequency than to their abstract linguistic functions. To investigate this possibility, we asked subjects to read a short essay for comprehension (Osterhout, Allen, & McLaughlin, 2002). We then averaged ERPs in two ways: as a function of word class (content and function) and as a function of word length. When we averaged the ERPs as a function of word class, we replicated the result reported by Neville and colleagues. Function words elicited a negative component at about 300 ms that was largest over anterior portions of the left hemisphere, whereas content words elicited a posterior-maximal N400 component (Figure 14.10a). However, when we averaged the ERPs as a function of word length, we found that the variation in amplitude and latency could be accounted for almost entirely by the single variable of word length (Figure 14.10b). This robust near-linear function is much more consistent with a "word-length" model than a "word-class" model; the word-length model predicts a continuous distribution, whereas the word-class model predicts a bimodal one.

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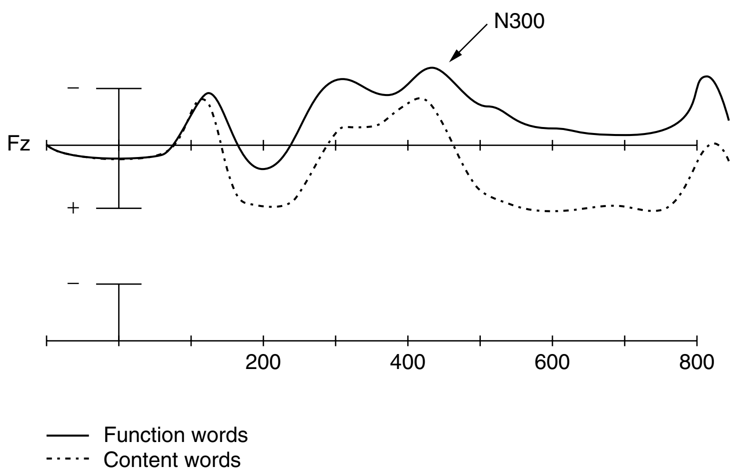
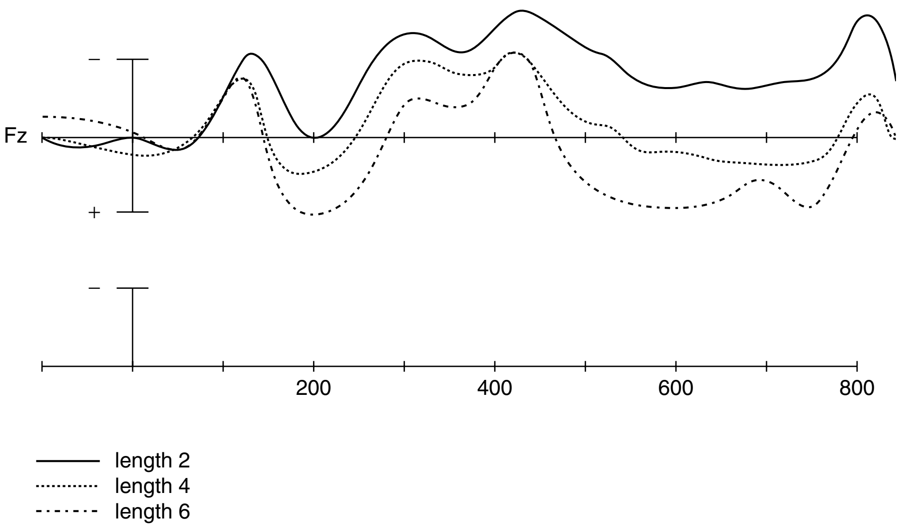



(A)




(b)

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***Figure 14.10.*** (A) ERPs (recorded over anterior midline site Fz) averaged as a function of word class. Adapted from "Words in the brain: Lexical determinants of word-induced brain activity," by L. Osterhout, M. Allen, and J. McLaughlin, 2002, *Journal of Neurolinguistics, 15,* 171–187. (B) ERPs averaged as a function of word length. Adapted from "Words in the brain: Lexical determinants of word-induced brain activity," by L. Osterhout, M. Allen, and J. McLaughlin, 2002, *Journal of Neurolinguistics, 15,* 171–187.

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Our second example concerns the observation, noted above, that certain types of syntactic (but not semantic or pragmatic) anomalies elicit a left anterior negativity (LAN) in addition to eliciting a P600 effect. Friederici and colleagues (Hahne & Friederici, 1999; Friederci, 1995, 2002) have proposed a two-stage functional model for these ERP effects. They claim that the LAN effect reflects a fast, automatic syntactic analyzer, and that the P600 effect reflects attempts at syntactic reanalysis.[10] Underlying these claims are three more basic claims: first, that the LAN effect is reliably elicited by violations of syntactic rules; second, that the LAN effect can be associated with a neural source in or near Broca's area (Friederici, Hahne, & von Cramon, 1998; Friederici, von Cramon, & Kotz, 1999; Friederici, Wang, Herrmann, Maess, & Oertel, 2000); and, third, that (on a single trial and within a single subject) the ERP response to syntactic rule violations is biphasic, involving an initial detection of the error (reflected in the LAN) and then an attempt to fix it (reflected in the P600).

Each of these claims is open to debate. First, a critical step in identifying the cognitive processes made manifest by some ERP effect is to identify the antecedent conditions that elicit or modulate it. However, the antecedent conditions that elicit the LAN effect are not clear. Although LAN effects are often reported in the response to a syntactic anomaly, there are a significant number of reports in which they are not reported (e.g., Ainsworth- Darnell, Shulman, & Boland,1998; Allen et al., in press; Hagoort, Brown, & Groothusen, 1994; Kuperberg, Holcomb, et al., 2003; McKinnon & Osterhout, 1996; Osterhout, Bersick, & McLaughlin, 1997; Osterhout, McLaughlin, & Inoue, 2002; Osterhout & Mobley, 1995; Takazawa et al., 2002).

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Second, the distribution of the LAN effect is somewhat variable and is not infrequently reported to have a bilateral (e.g., Friederici et al., 1999) or even a right-hemisphere-maximal distribution (e.g., Osterhout & Nicol, 1999, Exp. 2). This variability raises questions about the claim that the neural generators of the effect lie in or near Broca's area.

Third, even given the apparent existence of a LAN effect in the brain response to syntactic rule violations, it is not certain that individual subjects in individual trials show a biphasic response (LAN followed by P600) to these anomalies. This is because ERPs in the relevant reports were averaged (as is usually done) over subjects and trials. Thus, it is conceivable that the syntactic anomalies in Friederici's experiments elicited a negative-going effect in some subjects and a P600-like response in others. Such a finding would be problematic for Friederici's multistage model. A result much like this has been reported in one recent study (Inoue & Osterhout, in preparation). Inoue and Osterhout asked Japanese speakers to read sentences such as the following (written here in an English gloss):

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(6a) *Taro*-NOM *Hanako*-DAT *textbook*-ACC *to-buy said.*
*"Taro told Hanako to buy a textbook."*
(6b) **Taro*-NOM *Hanako*-ACC *textbook*-ACC *to-buy said.*
**"Taro told ??? to buy a textbook/Hanako."*

In Japanese, the verb typically appears at the end of the clause, and the nouns are attached to case markers specifying their grammatical and thematic roles. In both (6a) and (6b), the subject of the sentence is followed by two nouns. In (6a), these nouns are appropriately marked for dative and accusative roles, respectively. However, in (6b), both nouns are marked for the accusative role. If readers assume that both nouns are attached to the main verb, the second noun should be perceived to be anomalous.[11]

Therefore, ERPs to the second noun in sentences like (6a) and (6b) were of interest. When we averaged ERPs over all subjects, the response to the syntactically anomalous words seemed to be biphasic, involving both an anterior negativity between 300 and 500 ms, and then a large posterior P600 effect (Figure 14.11a). However, when subjects were divided into two groups based on the magnitude of the anterior negativity effect, ERPs averaged separately for these two groups revealed compelling individual differences: Those subjects who responded with a large negativity to the violations tended to show a very small P600 effect, whereas those that responded with a large P600 effect showed no evidence of a negativity (Figures 14.11b and 14.11c). Furthermore, the "anterior" distribution of the negativity largely disappeared when averages were formed over the two groups; in fact, the timing and distribution of the negativity elicited by these case anomalies were similar in this group of subjects to the timing and distribution of N400 elicited by semantic anomalies. Apparently, the anterior distribution was (at least to a degree) an artifact caused by component overlap (i.e., the posteriorly distributed P600 effect reduced the size of the negativity over posterior sites, but not over anterior sites).

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Obviously, it is far from clear how this finding relates to prior reports of a "LAN followed by P600" response to different types of syntactic anomalies in English and

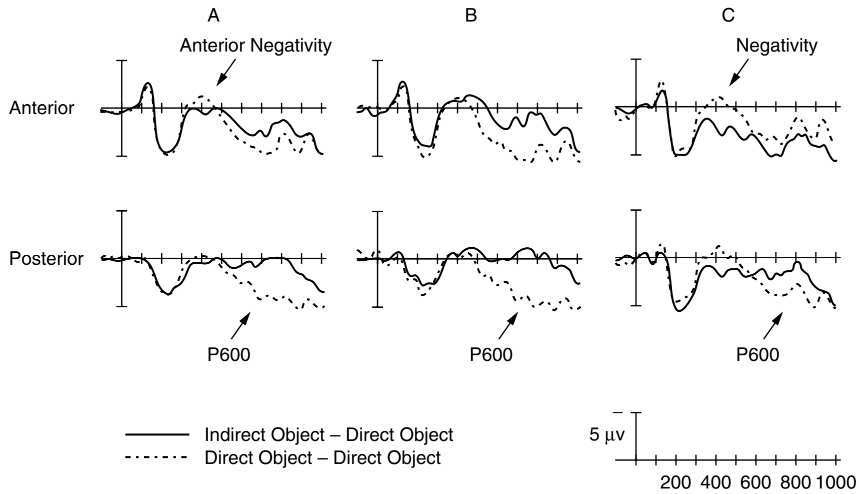


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*Figure 14.11.* (A) ERPs averaged over 20 subjects (recorded over an anterior and a posterior site) elicited by Japanese sentences of the form "Noun-Nominative Noun-Dative Noun-Accusative" (solid line) and "Noun-Nominative Noun-Accusative Noun-Accusative" (dashed line). Readers are predicted to encounter processing problems at the second of two consecutive nouns marked for accusative case. ERPs shown are those elicited to the second post-subject noun (Noun-Accusative) in each sentence type. (B) ERPs averaged over 10 subjects who showed the smallest-magnitude Anterior Negativity. (C) ERPs averaged over 10 subjects who showed the largest-magnitude Anterior Negativity.

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AU/PE: Lowercase "a," "b," and "c" used in text.

German. The relevant point, however, is that sometimes the grand average does not accurately reflect what occurs on a single trial or within a single subject. Unfortunately, if the sample is comprised of two or more populations, each of which responds differently to some event, this fact can be obscured by averaging over everyone.[12] This, in turn, can lead to erroneous conclusions about the distribution of an effect across the scalp, the ordering of events during a particular process, and the precise cognitive processes underlying some effect.

Perhaps it will turn out that the LAN effect is reliably elicited by syntactic anomalies, that it has a consistent scalp distribution, and that it is not an artifact of averaging over subjects. Is such evidence sufficient to justify the conclusion that the LAN effect directly manifests a fast, automatic syntactic analyzer? Unfortunately, no. This is because (as we noted above) the processes underlying the LAN effect (or the P600) might be correlated with, but indeterminately removed from, the syntactic processes themselves. One is still limited in the types of inferences that are licensed by the evidence; for example, by localizing the source or the LAN effect or the P600, one has not definitively isolated the source of syntactic processing. In all likelihood, definitive conclusions concerning the cognitive processes underlying these ERP effects will require converging evidence from other methods of investigation.

Friederici and colleagues provide another type of evidence that the LAN effect reflects the detection of a syntactic anomaly, whereas the P600 reflects syntactic reanalysis. They have shown that although the P600 is sensitive to stimulus manipulations (e.g., manipulating the proportion of anomalies within a list) and task manipulations (e.g., monitoring for a syntactic vs. a semantic problem), the LAN effect is not (Hahne & Friederici, 1999, 2002). Such a result is expected if the LAN reflects the actions of a fast, automatic syntactic analyzer, whereas the P600 does not. However, these demonstrations suffer from a potentially serious materials flaw. In both of their experiments, Hahne and Friederici presented their sentences as continuous natural speech. In such a paradigm, ERPs to several successive words will commingle. If these words are different across conditions, confounds are likely. In the Hahne and Friederici experiments, sentences in the control and syntactically anomalous conditions were comprised of sequences such as (1) *Das Brot wurde gegessen* (*The bread was eaten*) and (2) *Das Brot wurde im gegessen* (*The bread was in-the eaten*), respectively. The critical word was the verb *gegessen*. This comparison is problematic. For example, *wurde* and *im* might be different in phonological length and/or normative frequency, and thereby produce differences in ERPs that extend into the critical word epoch. Furthermore, it is likely that ERPs to *Brot* and *wurde* overlapped with the ERPs to *gegessen* in (1), while ERPs to *wurde* and *im* overlapped with the response to *gegessen* in (2). Nouns like *Brot* and high-frequency function words like *wurde* and *im* elicit quite different ERPs (e.g., Neville et al., 1992; Osterhout et al., 2002). Hence, one cannot assume that the reported differences in the ERPs to *gegessen* are due to the ungrammaticality of (2). Importantly, stimulus confounds of this sort would not be influenced by task and stimulus manipulations. This potential problem is not ameliorated by the use of a poststimulus baseline to equate the well-formed and ill-formed conditions (as was done by Hahne and Friederici); whatever preexisting differences are present continue to resolve themselves and continue to contaminate ERPs to the critical words, regardless of the choice in baseline. Although the existence or nonexistence of these confounds could probably be ascertained by examining the prestimulus portion of the epoch elicited by the critical word, Hahne and Friederici go counter to convention and do not plot this portion of the waveform.

It is undeniably true that the more we know about the cognitive events underlying some language-sensitive ERP effect, the more useful that ERP effect becomes. It is also true that erroneous hypotheses of this sort can have serious and unfortunate consequences, especially with respect to theory-building. We would like to be clear about what we are claiming: The hypotheses discussed in this section are useful. Even so, it is important to maintain a cautious and realistic attitude concerning the difficulties in attempting to validate such hypotheses.

Fortunately, these realities do not limit in any profound way the utility of ERPs for studying sentence processing. All that is needed to make progress is the discovery of ERP effects that co-vary systematically with principled stimulus manipulations (cf. Osterhout & Holcomb, 1995). With that in hand, one can use the ERP data to contrast functional claims about sentence processing even if one cannot make clear functional claims about the ERP effects themselves. The preceding two decades of work has provided convincing evidence of such effects and of their utility as tools for studying real-time sentence comprehension (see also chapter 13 by van Berkum, chapter 15 by Barber et al., and chapter 16 by Hoen and Dominey in this volume).

## 14.5 CONCLUSIONS

In our review, we have attempted to illustrate the advantages of ERPs for studying real-time language comprehension, both in native speakers and in adult language learners. We recognize, of course, that ERPs (like all methods of investigation) imperfectly reflect the cognitive and neural processes underlying human language. Because of this, it is wise to consider possible sources of converging evidence whenever possible.

Nonetheless, sentence comprehension (like all aspects of language comprehension) involves complex events that occur with great speed. A satisfying theory of sentence comprehension will explain how these events occur over time, in real time, as a person is trying to understand a sentence. The same is true for language learning, although in that case the theory must track changes that occur over two vastly different time scales: the time it takes a person to understand a word or sentence and the time it takes a person to learn the facts of the foreign language. A truly compelling theory will link these events to the brain, relying on direct measurement of brain activity. The primary (and perhaps unique) advantage of ERPs is that they provide us with a means for observing reasonably direct manifestations of some of the transient brain events that make up the core of language processing. ERPs also allow us to determine the "response selectivities" of these brain events through careful manipulation of linguistic stimuli. Given recent methodological advances, it appears that we might now be able to more compellingly relate these brain events to their underlying neural sources.

A cynically minded reader might argue that some of the novel insights described above are a bit too novel to be entirely believable. Surely we know that syntax is always first, that critical periods for language learning exist, and that fMRI is better suited than ERPs for localizing neural activity in the brain. We do not mean to espouse dangerously or ludicrously radical ideas. We do mean to suggest, however, that a particular method should be evaluated on the basis of its a priori suitability, its sensitivity to the phenomena of interest, and its ability to generate reproducible and theoretically interesting results. ERPs get high marks along all of these dimensions. ERPs (or any other method) should not be devalued or viewed skeptically simply because the data generated by the method seemingly contradict conventional beliefs. On the contrary, such methods should be valued more highly, as they provide the primary means for advancing our theoretical understanding.

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## *Notes*

1. Some event-related designs are probably better than others if the goal is to isolate the BOLD response to a specific word within a sentence. For example, a design in which sentences are identical across conditions except for a single critical word, and in which the hemodynamic response to critical words in successive sentences are sufficiently separated in time, might be one effective means for isolating word-specific BOLD responses. Also, recent efforts have been made to reduce the effective temporal

resolution (or "localization") of fMRI signals (Menon & Goodyear, 2001). However, whether these methods can be successfully applied to psycholinguistic research remains to be seen.

2. These studies did differ in how the fMRI data were treated statistically, which by itself could result in different conclusions across studies, even given similar BOLD signals.
3. Although the N400 and P600 effects to semantic and syntactic processing, respectively, are in fact highly reproduceable, and the antecedent conditions that elicit them are fairly well understood, this is perhaps less so for the LAN and other anterior negavitities elicited by syntactic anomalies. These anterior negativities are often not observed under conditions when they should be, according to some theories (e.g., Friederici, 2002). We comment further on this issue in the "Caveats and Cautions" section.
4. We computed the LORETA solutions using a grand-average waveform comprised of approximately 600 trials per condition (20 subjects times 30 trials per condition). The waveform was projected onto the Montreal Neurological Institute averaged brain. LORETA solutions were obtained for a single sample point representing the approximate peak of each ERP effect of interest.
5. Despite these interesting consistencies, the LORETA solutions should be viewed as preliminary until they are replicated. To the best of our knowledge, only two published studies have attempted to localize the N400 component (or the magnetic equivalent) using similar procedures (and none has attempted to localize the P600 effect). These studies produced results that differ from each other and from our results. Haan, Streb, Bien, and Roesler (2000) asked subjects to read pairs of words, some of which were semantically related, and estimated the current distribution for the N400 on an individual-subject basis. They found no consistent pattern across subjects. Dale et al. (2002) asked subjects to read sentences with a sentence-final word that was either fully acceptable or pragmatically implausible given the context. Source modeling placed N400m (the magnetic equivalent) onset (at ~250 ms) in the left posterior temporal lobe, and N400m peak (at 370 ms) in the left anterior orbital and frontopolar cortices. There are numerous procedural differences across studies that could account for these differences in outcome. Most fundamentally, both Haan et al. and Halgren et al. computed solutions on difference waves (in which the responses to the fully acceptable words were subtracted from the responses to the pragmatically anomalous words). However, the difference waveform is a mathematical fiction that might not preserve the underlying source information. Furthermore, Haan et al. presented word pairs rather than sentences, and Halgren et al. presented the critical words at the ends of sentences. It is not clear that these conditions will generalize to the conditions we used, in which the critical words were embedded in sentences. For example, by placing the critical words in sentence-final position, one potentially confounds the response to the anomaly with sentence wrap-up effects (cf. Osterhout, 1997, for more on this important point). Finally, Haan et al. and Halgren et al. both computed LORETA solutions on individual subject data, whereas we chose to compute them using grand-average data. Single-subject solutions probably preserve more precise spatial information; however, they also contain fewer trials and therefore more noise. LORETA cannot discriminate between signal and noise and models both; therefore, the validity of the procedure depends on reducing the noise as much as possible. This is most effectively done by using grand averages over subjects as the basis of the LORETA procedure. Evaluations of LORETA's reliability must take such methodological variation into account.

6. A reviewer suggested that the garden-path model could also account for these results. Perhaps the N400 effect is elicited only when the final/eventual analysis is implausible. It is conceivable that the implausible interpretation of (2a) is initiated, but rapidly detected as implausible. This could trigger rejection of the initial semantic interpretation before it is integrated along with an attempt to syntactically re-analyze the sentence. The syntactic re-analysis may be manifested in the P600 effect at the verb and the failure to integrate the initial interpretation may explain the absence of an N400 effect. The difficulty with this explanation is that a vast literature shows that N400 amplitude is exquisitely sensitive to pragmatic implausibility, and in fact is roughly linearly related to gradations of plausibility. Furthermore, the N400 effect typically onsets within ~250 ms after presentation of the anomalous word (which leaves little time for additional processing to occur). Therefore, it seems highly unlikely that implausibility would fail to be manifested in the N400 to the verb in sentences like (2a) if the verb was perceived to be pragmatically implausible.
7. It is worth mentioning that the temporal ordering of the N400 and P600 is seemingly inconsistent with the general assumption that syntactic processing precedes semantic processing. Caution is needed in using the temporal qualities of these and other ERP effects to make inferences about the timing of linguistic processes, due to the fact that the specific cognitive events underlying these all ERP-sensitive effects are not known. Nonetheless, it is interesting to note that linguistic (Jackendoff, 2000) and psycholinguistic (Bever & Townsend, 2001) theories have disputed the syntactocentric and syntax-first assumptions so prevalent in the field.
8. Several recent studies have examined ERP responses to linguistic anomalies presented in an L2 (e.g., Hahne & Friederici, 2001; Weber-Fox & Neville, 1996). These studies have in some cases produced results that are seemingly inconsistent with those reported here. For example, Weber-Fox and Neville examined the ERP response to linguistic anomalies in adult Chinese-English bilinguals who had been exposed to English at various ages, ranging from 1 to 16 years. All subjects had lived in the U.S. for a minimum of 5 years. ERPs were obtained in response to English pragmatic anomalies and several types of syntactic anomalies, including phrase structure anomalies. All groups displayed an N400 effect to pragmatic anomalies. However, the phrase structure anomalies elicited a P600-like effect only in bilinguals who were exposed to English before the age of 16; for those subjects who were first exposed to English after the age of 16, the phrase structure anomalies elicited an N400-like response. However, there are many differences between the Weber-Fox and Neville study and the study reported here, including language similarity (English-French vs. Chinese-English), study design (longitudinal vs. cross-sectional), quality and quantity of linguistic experience, the complexity of the stimuli, etc. We take our results as indicating that it is possible to see the rapid development of native-like brain responses to both pragmatic and syntactic anomalies given sufficient similarity between the L1–L2, and especially L1–L2 similarity in the syntactic rules being tested.
9. We want to stress the distinction between claiming that some ERP effect correlates highly with some stimulus manipulation and claiming that some ERP effect manifests some particular process. For example, we have claimed and continue to believe that the P600 effect is highly correlated with syntactic processing difficulty. We do not think that there is good evidence that the P600 effect reflects specifically structural reanalysis, as some have proposed.
10. In its most recent incarnations, Friederici's theory is actually a three-stage theory: the first stage is indexed by an "ELAN" effect between 100 and 300 ms, the second stage by the LAN effect, and the third stage by the P600 effect. These effects are

claimed to reflect detection of a word category anomaly, detection of a morphosyntactic anomaly, and syntactic reanalysis, respectively. We have reduced the stages to two for ease of exposition; our reasoning applies equally well to a two- or three-stage model.

11. Predictions about what type of brain response should be elicited by this anomaly depend largely on one's theory of Japanese grammar. Having two nouns assigned the same case (that is, the same thematic role) might be viewed as a syntactic problem or a thematic–semantic problem. The uncertainty about how a Japanese speaker would respond to these anomalies was one of the primary motivations for the experiment.
12. A simple statistical test exists for determining whether a biphasic LAN-P600 response seen in a grand average waveform is biphasic or monophasic for individuals. If subjects show either the LAN or the P600 (but not both) in response to a syntactic anomaly, then the effect sizes (i.e., the amplitude difference between the well-formed and ill-formed conditions) will be negatively correlated (indicating that as one effect gets larger, the other gets smaller). In the Inoue and Osterhout study, the correlation between the LAN and P600 effect sizes was robustly negative. This test can be applied to any relevant data set.