CHAPTER 23

Event-related brain potential (ERP) studies of sentence processing

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PROCESSING language is one of the major integrative acts at which the human brain excels, as it routinely orchestrates a variety of language representations and processes in real time. The intact human brain is the only known system that can interpret and respond to various visual and acoustic patterns such as *Can you open the window?* sometimes with a *No* and at other times by opening the window. Therefore, unlike researchers of other cognitive phenomena, (neuro)psycholinguists cannot avail themselves of invasive techniques in non-human animals to uncover the responsible mechanisms in the large parts of the (human) brain that have been implicated in language processing (Binder et al., 1997). Engagement of these different anatomical areas does, however, generate distinct patterns of biological activity (such as ion flow across neural membranes) that can be recorded inside and outside the heads of humans as they quickly, often seamlessly, and without much conscious reflection on the computations and linguistic regularities involved, understand spoken, written, or signed sentences.

23.1 Electrophysiology

The neural transmissions that underlie human communication involve the flow of charged particles across neural membranes. These currents generate electric potentials in the conductive media both inside and outside cells, which can be recorded as voltage differences between any two electrodes on the scalp. These measurements are especially sensitive to the currents at the receiving end of neurons, i.e. neurotransmitter-initiated voltage changes in the dendritic arbor of a neuron, which either increase the likelihood of its firing (excitatory post-synaptic potentials; EPSPs), or decrease it (inhibitory post-synaptic potentials; IPSPs). The scalp-recorded activity is the sum of the EPSPs and IPSPs from many neurons—primarily, neocortical pyramidal cells oriented in parallel—acting in concert and in like manner (Nunez 1981; Kutas and Dale 1997).

Because they involve the monitoring of groups of neurons "talking" to each other on a moment-by-moment basis at various scalp locations, electrophysiological measures are especially valuable for tracking the rapid ebb and flow of routine language processing. This involves a wide range of analytic and synthetic operations, including sensory-perceptual analyses and encoding, attentional allocation, retrieval from long-term storage, short-term storage, comparison-matching, mapping, inhibiting, organizing, and integrating different information types to create new structures—many processes that have ERP correlates in non-language tasks. These processes take place in a multi-layered system, with principles that apply to different levels of organization—sounds (phonetics and phonology), words (morphology), phrases and sentences (syntax), entire written or spoken texts (discourse and information structure), and meaning (semantics and pragmatics)—and unfold over different time-courses. All of these are temporally and spatially extended brain processes that operate on dynamic representations distributed throughout the brain and thus demand moment-to-moment monitoring. While the nature of the information representations, the timing of their availability and use, and their degree of independence and interaction are controversial, the need for a (neural) measure with a fine temporal resolution sensitive to psychological variables at intervals ranging from a few milliseconds to minutes is not.

Electrical brain activity offers a host of dependent measures in both the frequency and time domains. Until quite recently electrophysiological studies of language have been based primarily on the concept of evoked or event-related potentials, whereby some triggering event causes a change in the brain's response in a way that is relatable to its content and/or context (though see Altenmüller and Gerloff, 1998; Bastiaansen et al., 2002; Roehm et al., 2004 for alternative measures of electrical brain activity). The most common way to analyze such data is to form averages from the electroencephalogram coincident with many physically identical or conceptually similar individual trials (e.g. agreement violations), time-locked to some trigger event (generally, an external stimulus or a subject-generated movement). Random transient activity that is not synchronized to the triggering event tends to average out over many repetitions, leaving an electrical signal that presumably reflects activity causally related to the event: the event related brain potential or ERP (reviewed in Münte et al., 2000; Rösler, 2005).

Though ERPs are most often time-locked to event onsets, other critical time-points, such as word recognition points, presumed or real prosodic boundaries, moments of information delivery or ends of events can also serve as synchronizing triggers. Although most ERP analyses are based on cross-trial averages for 12-40 "similar" participants, item-based ERPs also can be created by averaging the brain's response to each single event across individuals. Müller and Kutas (1996), for example, used this approach to show differential brain processing for an individual's own name (presented only once experimentally) compared to many different individual names. Finally, though most language ERP data are scalp-recorded, one can record from neuropsychological patients using strip electrodes on the cortical surface or intracranial electrodes implanted in the brain (Halgren et al., 1994a; 1994b; Nobre et al., 1994; Fernandez et al., 2001; Halgren et al., 2002 for magnetic counterpart of ERP recordings). Such brain activity provides extremely sensitive indices of dynamic changes in brain states or operations as a function of various inputs, affording a means of tracking how and when the brain responds to events. ERPs provide an especially good link between the physical and mental world because they directly reflect brain activity whose parameters (amplitude, latency, topography) are sensitive to manipulations of psychological—for present purposes psycholinguistic—variables.

23.2 Language and the brain

Words or related items, such as meaningful pictures, sounds, or gestures, elicit characteristic patterns of electrophysiological responses reflecting the activation of perceptual, attentional, memory-related, and higher-order cognitive and neural processes that come into play as the sensory input is identified, attended, analyzed, linked to meaning, and related to larger-scale information structures (e.g. syntactic trees, situation models). Initial ERP features (sometimes called "components") to such items are especially sensitive to stimulus parameters (frequency, intensity, duration, location) and, in some cases, to the availability and allocation of attentional resources. At these early stages of processing, ERPs to language inputs are largely indistinguishable from those to non-linguistic inputs; indeed, it seems to take the brain some time to categorize a stimulus as letter-string-like (~95 ms), linguistic and/or potentially meaningful (~180 ms) (Schendan et al., 1998).

It is an oversimplification, however, to talk about "the" time course of language processing in the brain. Language stimuli are neurally complex, as they extend over space and time and contain multiple features and feature values that will typically be analyzed along multiple neural pathways that operate in parallel but with different functional characteristics and different time-courses. In this respect, psycholinguistic events (such as "lexical access," parsing, and meaning construction) are *processes* distributed over time and space, with no temporal or spatial boundary. Rather than being a momentary event, something like lexical access likely involves an accumulation of information that gradually separates word-like from non-word-like stimuli. Indeed, although lexicality-based ERP differences can first be observed around 200 ms, words and pseudo-words continue to elicit very similar ERP signatures (thus still being differentiated) well beyond 400 ms (Bentin et al., 1999). Similarly, psycholinguistic variables like word frequency affect processing in qualitatively different ways at multiple times. In the visual modality, frequency first affects the amplitude of a positivity around 150 ms (P150; Proverbio et al., 2004), a component presumed to reflect a visual processing stage sensitive to orthographic regularity. Frequency next impacts the latency of a negativity peaking from 240 to 400 ms post-stimulus-onset, with more frequent words eliciting an earlier peak than less frequent ones (Osterhout et al., 1997; King and Kutas, 1998; Münte et al., 2001). Slightly later, frequency affects the amplitude of a negativity (N400) with all else held constant. Still later, around 600+ ms, high-frequency words are associated a greater positivity, though only under some task conditions (Rugg, 1990).

As illustrated for word frequency, with increasing processing time, electrophysiological responses to language stimuli depend less on physical aspects of a stimulus and more on the nature of the information (semantic, syntactic) linked to that stimulus, the context, and task demands. A number of components that are sensitive—though not necessarily specific—to linguistic manipulations or representations have been identified. These provide functionally specific indices of cognitive and neural activity that can be used under well-defined experimental conditions to test certain types of hypotheses about the nature and separability of psycholinguistic processes and representations, even if we do not yet appreciate the exact functions indexed.

In the next sections, we introduce in turn the ERP responses that have played an important role in the study of language processing. After describing each component and discussing its functional and neurophysiological bases, we examine some of the key issues that studies using that component have addressed. We begin with the N400 (section 23.3.1), an ERP response that has been closely linked to the processing of meaning, and we describe studies using this measure that have addressed context effects in meaning construction (23.3.2), hemispheric differences in sentence processing (23.3.3), and non-literal language processing (23.3.4). We next describe a set of ERP components (the left anterior negavitity (LAN), the early left anterior negativity (ELAN) and the P600) that have been linked to various aspects of syntactic processing (23.4.1) and discuss what they have revealed about parsing (23.4.2). In section 23.5 we introduce components that unfold over longer timecourses (slow potentials and the closure positive shift (CPS)), and describe their contributions to our understanding of how information is integrated across multiple words. We end with cursory mention of what ERPs have revealed about plasticity and learning in language (section 23.6).

23.3 **Processing language meaning**

23.3.1 **N400**

The N400, a relative negativity seen between 250 and 550 ms, was originally discovered in response to semantic anomalies ending sentences (e.g. *I take my coffee with cream and dog*; Kutas and Hillyard, 1980a), but is now considered to be part of the default electrophysiological response to potentially meaningful items (words, pseudowords, pictures) in any modality. Content words generally elicit larger N400s than function words (though see King and Kutas, 1995); among function words, those with richer lexical semantic content elicit larger N400s (Kluender and Kutas, 1993). N400s generally have centroposterior maxima, though their scalp distributions vary with stimulus features (e.g. more anterior for concrete than abstract words; Kounios and Holcomb, 1994; Holcomb et al., 1999) and input modality (e.g. more central for auditory stimuli; McCallum et al., 1984; Holcomb and Anderson, 1993). Distributional differences notwithstanding, N400 amplitude is modulated by a host of factors that render particular words/concepts more accessible, e.g. word frequency, repetition, neighborhood size, sentence position, presence of lexically or semantically associated words, and predictability within a sentence or larger discourse structure. The ERP in the region of the N400 is also sensitive to orthographic, phonological, and morphological relationships (Kutas and Federmeier, 2001; Dominguez et al., 2004; Kutas et al., 2007) and unexpected case morphology (Münte and Heinze, 1994; Hopf et al., 1998). N400s typically are not observed to grammatical violations (if these do not impact meaning) or to violations of prosody (Astesano et al., 2004). N400s have typically not been observed in music (Besson and Macar, 1987) or for non-linguistic manipulations of meaningful stimuli (improbable word font changes; Kutas and Hillyard, 1980b), but are elicited by unrelated environmental sounds (Van Petten and Rheinfelder, 1995), incongruent picture story endings (West and Holcomb, 2002), and by improbable objects in video clips of daily life events (Sitnikova et al., 2003).

N400 relatedness and repetition effects are significantly attenuated by attentional selection based on space or color (McCarthy and Nobre, 1993).

Nonetheless, they are seen even when the prime or target stimuli appear so quickly as to not leave any declarable memory trace (as with masking; Stenberg et al., 2000; Hohlfeld et al., 2004; Holcomb et al., 2005; during the attentional blink; Luck et al., 1996; Rolke et al., 2001). These results suggest that the processes reflected in the N400 are neither fully automatic nor fully controlled. Overall, neuropsychological, intracranial, and magnetoencephalographic data suggest that a large portion of the temporal lobes, encompassing areas critical for access to semantic memory, are responsible for the scalp-recorded N400, with a larger contribution from the left hemisphere than the right (for review see Van Petten and Luka, 2006). Its variable topography suggests that scalp-recorded N400s may reflect a set of spatially distributed but temporally coincident neural processes involved in meaning construction, though localization inquiries to date have been limited to very basic N400 effects.

23.3.2 Context effects in meaning processing

Though specific neither to language nor to semantics, the extant data suggest that N400 amplitude is a general index of the ease or difficulty of retrieving stored conceptual knowledge associated with a word (or other potentially meaningful stimulus), which is dependent upon both the stored representation itself and the retrieval cues provided by the preceding context. It is thus often linked to semantic or contextual integration processes (Chwilla et al., 1995). The N400 has played an especially important role in providing insights into meaning construction — how and when meaning is gleaned from words, sentences, and discourses (note: the nogo N200 component is also used to track word processing; Schiller et al., 2003).

One key question has concerned the time-course with which word information is used to build a message level meaning. The construction of a higher-order meaning representation might proceed in spurts, with incoming word information buffered until major linguistic (phrasal, clausal, sentential) boundaries trigger integration. Alternatively, sentence processing might proceed incrementally, with higher-order representations built and updated with each incoming word. The presence of an N400 within 200 or so ms of the onset of a lexical-semantic anomaly has consistently supported the immediacy assumption for semantic analysis. Moreover, even for words which are congruous in their context, N400 amplitudes decline progressively with the eliciting word's ordinal position within the sentence, presumably reflecting the incremental build-up of contextual information as sentences unfold (Van Petten and Kutas, 1990). Critically, such a decline is *not* observed for syntactic prose or scrambled sentences that provide a continuous stream of lexical information but no opportunity to build a coherent message-level representation (Van Petten and Kutas, 1991). Moreover, contextual influences on spoken words occur before the acoustic information is sufficient to uniquely identify the words (Van Petten et al., 1999), Such findings strongly suggest that sentence interpretations are immediate and computed incrementally, though they do not inform current debates about what types of intermediate representation (semantic, grammatical, etc.) are constructed and when, if ever, each word is processed "fully" (Frazier, 1999). Studies looking at slow potentials that evolve over the course of clauses and sentences also provide support for incremental processing, pointing to a critical role for working memory (see section 23.5 below). ERP data also suggest that clausal, prosodic, and sentential boundaries may indeed constitute important points for some integrative processes (Kutas and King, 1996; Steinhauer, 2003)—perhaps (speculatively) because the representation built at each word is not always complete.

Since the discovery of the N400 difference between contextually congruent and anomalous words in sentences, ERPs have played an important role in uncovering the nature, time-course, and functional identity of the ubiquitous context effects on word processing. ERP measures are especially useful in adjudicating between different theoretical stances on whether context effects in connected discourse arise via the same mechanisms as context effects in word pairs (such as lexical priming), or via wholly distinct mechanisms (message-level constraints), or some combination thereof. Whereas behavioral data are mixed (Duffy et al., 1989; Traxler et al., 2000), ERP data unequivocally show that whether the context is a single word, a sentence fragment, or a larger discourse, context effects manifest in qualitatively similar electrophysiological responses, implicating similar neural mechanisms. Regardless of level, context modulates the N400 region of the ERP: lexically related, sententially congruent, and discourse-appropriate items are all associated with relatively less N400 activity, in a manner graded by contextual strength (reviewed in Kutas and Federmeier, 2000). Moreover, all context effects start at about the same latency (~150–200 ms), with the impact of discourse- and sentence-level contexts occasionally preceding that of a lexically associated word. Van Petten (1993) embedded pairs of associated or unassociated words in congruent or anomalous (syntactic prose) contexts, and found that both lexical and sentential constraints reduced N400 amplitudes in a similar fashion, and additively. Thus, though lexical and message-level constraints can operate in parallel, they have qualitatively similar impacts at some processing stages. However, the nature of the interaction between lexical and sentential information has been found to vary across age groups and individuals, as well as with sentence position and contextual strength (Van Petten and Kutas, 1990; Van Petten et al., 1997; Federmeier et al., 2003). Indeed, lexical effects—of word frequency (Van Petten and Kutas, 1990) or lexical association (Van Petten et al., 1997), for example—are subsumed by message-level constraints when these are sufficiently strong, indicating that lexical priming does not necessarily have temporal or functional priority over message-level processing. More generally, such patterns highlight the importance of examining language processing at multiple levels—word, sentence, discourse—as findings at one level do not necessarily generalize well to others. ERP researchers (like other psycholinguists) have only begun to appreciate and explore the availability of different sorts of contextual information (e.g. shared assumptions and common knowledge structures between familiar language partners in a rich environment) and the critical role that they must play in the processing of natural language, which is often impoverished—i.e. noisy, missing information, and with information dropped or referred to with relatively "empty" placeholders.

Given that message-level information has a role in word processing, an important question becomes how that information is used. Many language comprehension models seem to explicitly or implicitly assume that the influence of context is relatively passive, occurring fairly late in word processing, after a word's features have already been accessed, i.e. post-lexically. On such accounts, word processing including access to meaning, proceeds in a bottom-up fashion, largely, if not completely, unaffected by sentence- or discourse-level information (Forster, 1981). Context merely eases the integration between matching features in the conceptual information activated via bottom-up processes and the message-level representation built of prior context. Alternatively, context information may be used in a more top-down fashion, such that features of upcoming words or concepts are at least partially activated prior to their occurrence, thereby affecting processing even during early ("prelexical") stages of word processing. A number of recent ERP studies have provided solid evidence supporting this latter view. Federmeier and Kutas (1999a), for example, recorded ERPs as participants read pairs of sentences designed to elicit a particular noun from a particular semantic category (e.g. *Every morning John makes himself a glass of freshly squeezed juice. He keeps his refrigerator stocked with ...*). Three types of sentence endings were used: the expected completion (*oranges*), an unexpected completion from the same semantic category (*apples*), and an unexpected completion from a different semantic category (*carrots*). N400 amplitudes were smaller for expected as compared with unexpected completions; however, among unexpected completions amplitudes were smaller to items from the same category than from a different category, even though these were matched for contextual fit (plausibility). Furthermore, the degree of facilitation for the within-category violations was graded by the level of participants' expectations for the most common completions. As these were not actually presented, their impact on the processing of the categorically related words suggests that comprehenders use context to actively prepare for—i.e. predict—semantic features of upcoming items (see Figure 23.1).

Wicha and her colleagues (2003a; 2003b; 2004) demonstrated that readers and listeners also develop expectations about syntactic features (grammatical gender) of a likely upcoming word in Spanish. As participants processed sentences that were predictive of a particular noun, ERP effects were observed on the preceding article when its gender disagreed with that of the contextually expected—but not yet presented—upcoming word. Van Berkum et al. (2005) likewise showed prediction-based effects (early positivity) on ERPs time-locked to suffixes of gender-marked Dutch adjectives when these mismatched the syntactic gender of the contextually expected noun in congruent, spoken sentences; critically, these effects vanished in the absence of discourse context. Finally, DeLong et al. (2005) capitalized on a phonological regularity of English—words beginning with vowel-sounds are preceded by *an*, whereas words beginning with consonant-sounds are preceded by *a*—to look for prediction of word-forms with specific phonological content (lexemes), and not just their semantic and syntactic properties. The N400 to the indefinite article was well-predicted by the probability of its occurrence and that of

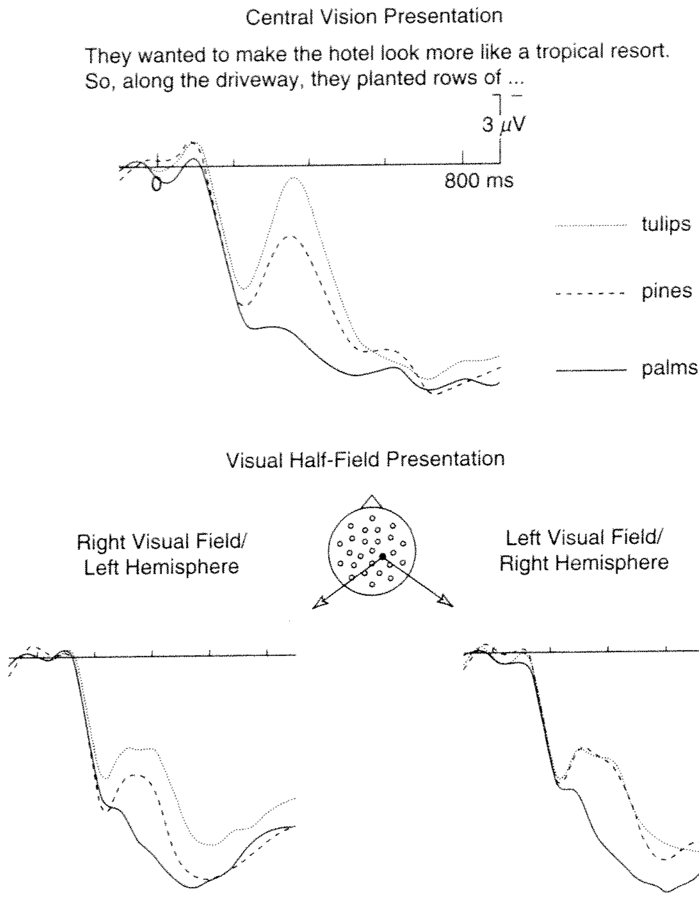

Figure 23.1 TOP: Grand average ERPs (N=18), shown at a representative right medio-central scalp site (see head icon), to the final words of sentences read for comprehension one word at a time in the center of the screen. As illustrated by the example, sentences were completed with three ending types: (1) *expected exemplars*, the highest Cloze probability completions for these contexts; (2) *within-category violations*, unexpected and implausible completions from the same semantic category as the expected exemplars; and (3) *between-category violations*, unexpected and implausible completions from a different (though related) semantic category. All unexpected items elicited increased negativity between 250 and 500 ms post-stimulus onset (N400) relative to the expected exemplars (solid line). However, despite equivalent Cloze probabilities and plausibility ratings, the N400 to the two unexpected items differed as a function of their semantic similarity to the expected completions. Within-category violations (dashed line), which shared many semantic features in common with the expected exemplars, elicited smaller N400s than did between-category violations (dotted line), which had less semantic feature overlap. The results suggest that the comprehension system anticipates and prepares to process the semantic features of likely upcoming words.

BOTTOM: Grand average ERPs (N=18) from a different group of participants who read these same sentences for comprehension in a visual half-field presentation paradigm. Sentence-context words were presented at central fixation, whereas sentence-final targets were presented with nearest edge two degrees to the left or right of fixation. Words presented to the left visual field travel initially to the right hemisphere and vice versa. The response to target words presented to the right visual field/left hemisphere (shown on the left side of the figure) yielded the same pattern as that observed with central fixation. This pattern is indicative of a "predictive" strategy, in which semantic information associated with the expected item is pre-activated in the course of processing the context. The response to targets presented to the left visual field/right hemisphere (shown on the right side of the figure) was qualitatively different: expected exemplars again elicited smaller N400s than violations, but the response to the two violation types did not differ. This pattern is more consistent with a plausibility-based integrative strategy. Taken together, the results indicate that the hemispheres differ in how they use context to access information from semantic memory during on-line sentence reading.

the upcoming—not yet seen but clearly anticipated—noun, estimated from offline Cloze procedures. These studies have in common that they find ERP influences from words never presented or not yet presented at the time of measurement—i.e. evidence of pre-activation.

23.3.3 Hemispheric differences in sentence processing

Though a predictive strategy may be more efficient and robust in the face of noise/ambiguity, those who have argued against it maintain that it would yield too many mistakes and/or would tax certain cognitive resources. The ideal, then, would be to use *multiple* strategies in parallel, and there is increasing evidence that the brain might do just that, by distributing processing across the two cerebral hemispheres.

Since Paul Broca's discovery (in 1861) of an association between fluent, articulate speech and the left frontal operculum, the critical role of the left hemisphere (LH) for language processing has become one of the most striking and oft-cited examples of hemispheric specialization in humans. However, recent evidence suggests that both hemispheres make critical, albeit different, contributions to aural/oral and visual/manual language comprehension. Non-invasive spatial neuroimaging data have revealed language-related activation in brain areas outside the regions classically associated with aphasia, including some in the right hemisphere (RH) (Ni et al., 2000). Moreover, some of these data, particularly those collected during the comprehension of complex narratives (St George et al., 1999; Robertson et al., 2000) or non-literal language (Bottini et al., 1994), show bilateral activation with a predominance of RH activity. One must then ask what language functions the RH supports, how these differ from LH functions, and what role they play in normal language processing.

Several studies have now combined ERP measures with visual half-field (VF) presentations traditionally used to examine hemispheric differences. This technique takes advantage of the fact that information presented in the visual periphery (more than a half degree from fixation) is initially received exclusively by the contralateral hemisphere, eliciting processing biases that persist into higher-order aspects of cognition. While such behavioral studies examine only the extent of preferential or predominant processing by one hemisphere over another, those with concurrent brain measures license decomposing the lateralized contribution of the processes underlying performance. Since these processes occur quite early—and many very quickly—the temporal resolution of ERPs (and their magnetic counterparts) gives them a unique advantage in assessing not just whether both hemispheres respond to particular types of stimulus or under particular task conditions, but whether those responses occur rapidly enough to contribute to a particular function as it unfolds.

Coulson et al. (2005) used the combined half-field ERP method to examine each hemisphere's sensitivity to lexical and message-level information. In one experiment, participants viewed associated and unassociated word pairs; primes were presented centrally and targets lateralized to the left (LVF) or right (RVF) visual fields. In a second experiment, these same word pairs were embedded in sentence contexts, wherein the targets formed plausible and implausible message-level completions. For word pairs out of context, robust effects of association, with identical onsets, were found on N400s for presentation to both VFs, though slightly bigger after RVF/LH presentation. This suggests that the LH is better equipped to make use of word-level information when that is the only context available. However, association effects for these same word-pairs within sentences were largely superseded by sentential plausibility in both VFs, suggesting that both hemispheres are sensitive to message-level information. Association exerted a very small effect on the N400s to incongruent endings for both VFs; association effects in congruent sentences, however, were only apparent for LVF/RH stimuli. Thus, when higher-level context information was available, LH processing seemed to be less affected than RH processing by the word-level cues.

Federmeier and Kutas (1999b; 2002) found that while both hemispheres use message-level context information for word processing, they do so differently. In response to lateralized presentation of the final words of the sentence pairs and ending types used to examine predictive processing, as previously described (section 23.3.2), there were equivalent-sized N400 congruency effects (difference between expected items and out-of-category violations), with similar timing in both VFs (bottom of Figure 23.1). This result suggests that RH word processing is sensitive to message-level information. However, priming for the semantically related but contextually implausible endings (within category violations) was greater following RVF/LH presentation; indeed, in the LVF/RH, responses to the two violation types were identical. In other words, only the LH showed the pattern associated with prediction; the RH's pattern, instead, was consonant with the bottom-up plausibility of the words in their sentence contexts. Since a similar pattern was obtained with lateralized line drawings, it appears to reflect something general about how each hemisphere uses sentential context rather than something specific to reading (Federmeier and Kutas, 2002).

ERP comparisons to laterally presented congruent words differing only in the extent to which they were contextually constrained suggest that predictive processing by the LH may extend to pre-semantic levels of analysis (Federmeier et al., 2005). Increased contextual constraint facilitated N400s equivalently in both VFs, providing added support for the hypothesis that the RH can build and make use of detailed message-level language information. VF-based differences in constraint effects on higher-level visual processing, however, were evident on the frontal P2, a positive potential peaking around 200 ms. P2 modulations have been linked to the detection and analysis of visual features in selective attention tasks (Hillyard and Münte, 1984; Luck and Hillyard, 1994), with larger amplitudes to stimuli containing target features. P2 responses to strongly constrained targets were enhanced only with RVF/LH presentation. These findings support the hypothesis that LH processing of sentences provides top-down information, affording more efficient visual extraction from highly expected targets. Such top-down information seems to be less available for stimuli projected initially to the RH.

In combination with behavioral studies, ERP data suggest that the right hemisphere—like the left—is able to understand words and their relationships, and to use word information to build higher-level meaning representations, albeit differently. ERPs are beginning to reveal the consequences of these differences for multiple stages of word perception and language processing. More generally, such research points to the real possibility that that there may not be a single model of language comprehension; instead, multiple mechanisms may be employed in parallel, distributed across the hemispheres. Though more perplexing for psycholinguists, such multiplicity is an effective strategy for the brain to employ, since some redundancy is useful and since it may help optimize the trade-offs engendered by choosing either a serial, bottom-up or a more interactive (bottom-up plus top-down) processing strategy. However, this also means that information from multiple processing pathways must ultimately be brought together for an understanding of hemispheric integration as well as sentence processing. These are processes we are still far from understanding, but which we assume must be highly time-dependent, since information arriving simultaneously at the same place can interact, while information that does not, cannot.

23.3.4 Non-literal language processing

The potentially different contributions of the hemispheres to language processing also have been hypothesized to be critical for figurative language processing. A long-standing distinction has been made between literal and non-literal language, which includes figurative devices such as metaphors, idioms, indirect requests, irony, and sarcasm. At issue is whether identical mechanisms can account for the comprehension of literal and figurative language, which neuropsychological data have traditionally linked to the left and right hemispheres, respectively. On the standard pragmatic view, all language is initially interpreted literally, with figurative construal pursued only after the literal construal fails (Searle, 1979). From this it follows that literal and figurative language are processed with qualitatively different neurocomputational mechanisms, with those that compute literal meaning acting first. These predictions have generally not been supported by reaction time data; substantial evidence indicates that metaphor processing is not necessarily slower nor always optional (Gildea and Glucksberg, 1983; Gibbs et al., 1997). Current processing models of metaphor comprehension thus assume that literal and non-literal language comprehension occur with similar time course, involve the same processing mechanisms, and are sensitive to the same variables (Gibbs, 1994; Wolff and Gentner, 2000).

Equivalent reaction times, however, do not necessarily mean equivalent processing (resource) demands, nor can they be unquestionably taken as evidence for identical neurocomputational mechanisms. These reasons alone would suffice to warrant electrophysiological comparisons of the processing of literal vs. metaphorical statements. If metaphorical and literal processing elicited waveforms differing in shape, and/or scalp topography, we would conclude that they do not engage identical mechanisms. Alternatively, if the only difference was in a temporal shift of some component, we might conclude that one construal precedes the other. However, across a handful of studies, ERPs elicited by words processed metaphorically are remarkably similar to those elicited by words processed literally, with only a slightly larger, though no more or less lateralized, N400 to metaphors. Context attenuates N400 amplitudes similarly in metaphorical and literal sentences (Pynte et al., 1996). These results suggest qualitatively similar processes of meaning construction—e.g. retrieving stored conceptual knowledge and contextual integration—for literal and metaphorical sentences, though with more effort for metaphors.

Further ERP evidence that literal and metaphorical interpretations can be available with similar time-courses comes from ERP recordings as participants decided whether sentences were *literally* true or false (Kazmerski et al., 2003). Both types of literally false sentence—anomalous sentences that could not be interpreted metaphorically (*The rumor was a lumberjack*) and metaphors (*The beaver is a lumberjack*)—elicited large N400s relative to literally true sentences. However, the N400s (and associated reaction times) to metaphors were smaller, at least in those with high IQs, consistent with automatic extraction of figurative meanings during the construction of literal meaning. Individuals with lower IQs, by contrast, produced slightly smaller positivities to true sentences, and same-sized N400s for metaphors and anomalies, along with good off-line metaphor comprehension. Clearly, metaphorical processing is not always obligatory or automatic, with availability of resources to meet processing demands being a critical factor.

Coulson and Van Petten (2002) reasoned that if similar mapping operations (noting correspondences between target and source domains, selecting relevant characteristics, and filtering out or actively suppressing irrelevant ones) are invoked by both literal and metaphorical sentences, but to varying degrees, it should be possible to find some literal sentences that also depend on these processes. To that end, they constructed sentences describing situations where one object was substituted, mistaken for, or used to represent another (*He used cough syrup as an intoxicant*), which required the setting up of mappings between two objects and the domains in which they commonly occur (literal mapping). These literal mapping processes were presumably intermediate to the intricate mapping used in metaphor comprehension (*He knows that power is a strong intoxicant*), and the minimal, if any, mapping used in the comprehension of literal sentences (*He knows that whiskey is a strong intoxicant*). And sentence-final words did indeed show graded N400s—smallest for literal sentences, largest for metaphors, and intermediate for the literal mapping condition. These data suggest that it is the complexity rather than uniqueness of mapping and conceptual integration processes that sometimes calls for more effort to understand metaphorical (than literal) expressions.

Essentially the same sorts of question have been asked regarding joke comprehension. Are jokes in fact neurocomputationally special? ERPs to final words of one-line jokes and non-joke straight sentences (matched on Cloze probability) do reliably differ, though the way in which they differ varies with contextual constraint, the extent to which individuals got the joke, verbal skills, handedness, and visual field of presentation (Coulson and Kutas, 2001; Coulson and Lovett, 2004; Coulson and Wu, 2005). Coulson and Williams (2005), for example, observed larger N400s to jokes relative to non-jokes only when punchlines were presented to the RVF/LH; with LVF/RH presentations, jokes and low Cloze endings elicited equivalent-sized N400s relative to high Cloze endings. ERP data, overall, indicate substantial overlap in joke and non-joke processing, with no evidence for any serial two-stage account of joke processing. Though some aspects of joke comprehension seem easier for the right hemisphere, this seems to be a matter of degree. Perhaps the most valuable lesson for all language studies is the need to keep track of whether people comprehend, and of their verbal ability, handedness, and gender, among other factors (e.g. working memory span), when assessing language comprehension.

23.4 **Processing language form**

23.4.1 **LAN, ELAN, and P600**

While the N400 has been linked to the processing of a word at the level of meaning, other ERP responses have been more closely associated with syntactic processing, honoring at least some processing, if not representational, distinctions between the two (see Figure 23.2). Syntactic anomalies are sometimes accompanied by an enhanced negativity over anterior scalp sites, of variable onset, duration, and topography (sometimes with a left hemisphere focus) called the Left Anterior Negativity (LAN). Occasionally, stretches of sentences with relatively complex hierarchical structures (e.g. embedded clauses) are accompanied by sustained frontal negativities typically

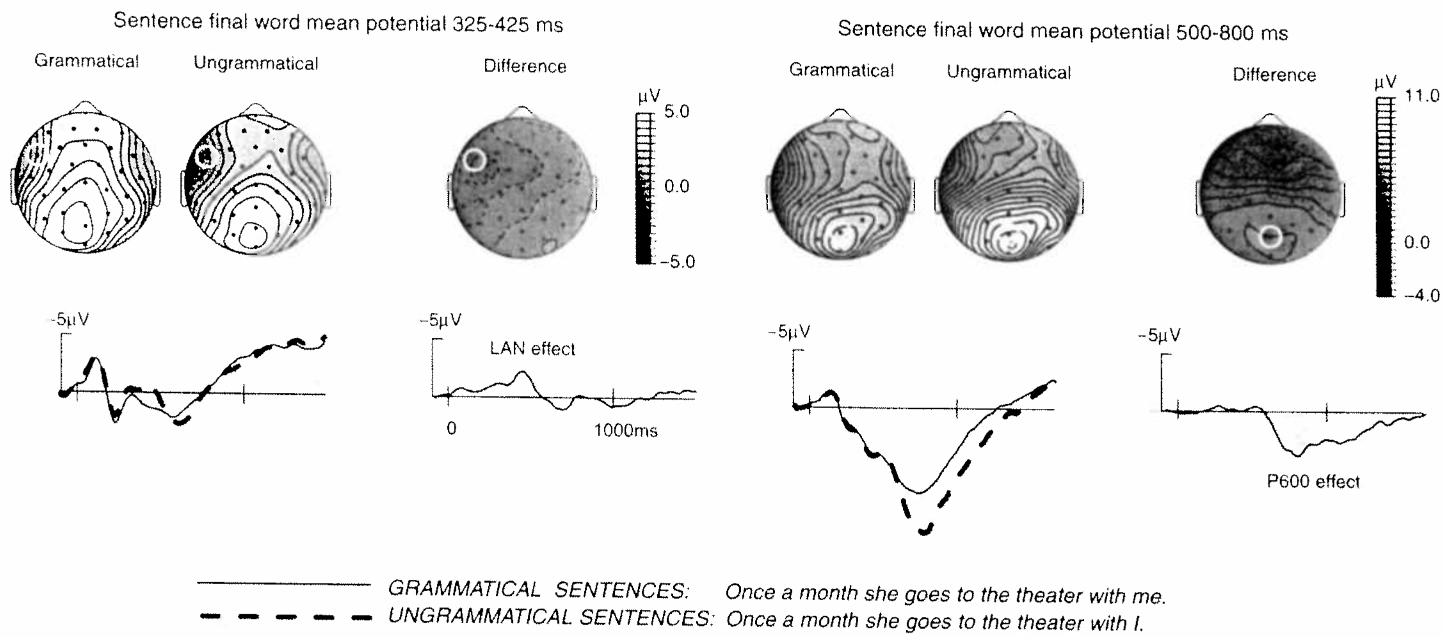

Figure 23.2 Representative data depicting a left anterior negativity (LAN) and a P600 to grammatical violations. Shown are grand average ERPs (N=16) to sentence-final words of grammatical and ungrammatical sentences which participants read one word at a time and to which they made a "sensible and grammatical" delayed response. Grammatical violations included both incorrect case markings on pronoun, as in the sample sentence, and number mismatches on verbs. Included in the stimulus set were semantically congruent and anomalous sentence endings. Spatial distribution of the mean amplitudes (shaded area) for one left frontal site between 325 and 425 ms post-final word onset and one mid-line parietal site between 300 and 500 ms (sites marked by a white circle) are shown for grammatical endings, ungrammatical endings, and the difference ERP calculated by subtracting the grammatical ERP from the ungrammatical ending ERP. (Source: unpublished data from dissertation by D. Groppe.)

spanning several words (see also section 23.4.2 below), and have typically been related to working memory processes (Fiebach et al., 2002; Felser et al., 2003); the precise relationship between the local, phasic LAN activity and these sustained slow negativities remains an open question.

Some researchers have further distinguished the phasic negativities occurring between 100-300 ms post-word onset—an early LAN, or ELAN, associated with word category errors—from those occurring between 300 and 500ms or later, associated with morphosyntactic errors (Friederici, 2002). Both this division and the functional significance of these negativities are controversial. On a domain-specific construal, LAN activity globally reflects violations of syntactic well-formedness. Alternatively, on a domain-general construal, the negativity reflects primarily working memory processes (Kluender and Kutas, 1993), perhaps with a fronto-central storage component, and a fronto-temporal retrieval component (Matzke et al., 2002), on the assumption that the extended negativity is primarily the sum of local LANs.

More precisely, some researchers identify the ELAN with an early, automatic local phrase structure-building process, during which word category information is used to assign an initial syntactic structure; its latency has been said to vary with when information about word class becomes available (Friederici et al., 1996). Consistent with this proposal, an ELAN is only seen in response to closed-class items and phrase structure violations, even in pseudo-word sentences (Hahne and Jescheniak, 2001), is insensitive to attentional manipulations, impervious to the proportion of ill-formed experimental sentences (Hahne and Friederici, 1999), does not appear until 6 years of age (Hahne et al., 2004), and is severely compromised by damage to anterior regions of the left hemisphere, as in Broca's aphasics (ter Keurs et al., 2002; Kotz and Friederici, 2003). The generality of ELAN across languages remains unknown (see Neville et al., 1991 for ELAN to phrase structure violations in English, but Hagoort and Brown, 2000 for a failure to find such evidence in Dutch).

The later LAN, while likewise elicited by phrase structure violations, also has been observed for morphosyntactic violations of various types in several languages: violations of agreement (Angrilli et al., 2002; Roehm et al., 2005), case markings (Osterhout et al., 1996; Coulson et al., 1998a; Münte, Heinze et al., 1998), and verb inflections (Gunter et al., 1997: exp. 3). These results are consistent with the proposed link between the later LAN and morphosyntactic violations and the hypothesis that it indexes a stage subsequent to initial phrase structure-building, varying in amplitude with processing difficulties in using syntactic information such as subcategorization and inflectional morphology (number, gender, case) in thematic role assignment. Morphosyntactic violations, however, appear not to be sufficient or necessary for LAN elicitation. For example, some violations of subject–verb agreement (e.g. Hagoort et al., 1993; Osterhout et al., 1996; Münte et al., 1997; Coulson et al., 1998a; Kemmer, et al., 2004) and some verb inflection violations (Gunter et al., 1997: exp. 1; Osterhout and Nicol, 1999) do not yield any LAN activity. Moreover, LAN activity has also been observed to syntactic violations that are not morphosyntactic in nature, such as argument structure violations (Friederici and Frisch, 2000: exp. 1), and to subcategorization violations (Hagoort and Brown, 2000: exp. 2), as well as in syntactically complex sentences (filler gap constructions) without violations (Kluender and Kutas, 1993). Finally, a LAN has reportedly been seen in well-formed but complex sentences, to lexical ambiguities (Hagoort and Brown 1994), and perhaps even during multiplication (Jost et al., 2004).

Syntactic violations of various sorts also elicit a relatively late, positive potential that is often largest over central and parietal sites, initially labeled the "syntactic positive shift" (SPS) but now called the "P600" (Neville et al., 1991; Osterhout and Holcomb, 1992; Friederici et al., 1993; Hagoort et al., 1993; Osterhout and Hagoort, 1999). The P600 typically occurs between 500 to 800 ms, usually as a broad peakless shift, though it can peak as early as 325 ms. P600s have been observed in response to violations of subject–verb agreement (even in syntactic prose), verb or case inflection, and phrase structure, among others. It is, however, clearly not specific to syntactic violations per se: P600s are also seen in syntactically well-formed sentences that have a non-preferred syntactic structure (e.g. at the disambiguating word following a temporary syntactic ambiguity), and in unambiguous but syntactically complex sentences (Kaan et al., 2000; Frisch et al., 2002; Felser et al., 2003).

P600s to number agreement violations are attenuated in Broca's aphasics with severe syntactic deficits (Wassenaar et al., 2004), and P600s to verb argument structure violations are severely compromised in individuals with basal ganglia damage (Kotz et al., 2003). Accordingly, the P600 is presumed to reflect some aspect of syntactic processing difficulty: e.g. a controlled process of syntactic reanalysis or repair given a mismatch between lexico-semantic and syntactic representation (Friederici, 2002); an inability of the parser to assign the preferred structure (Hagoort et al., 1993); general syntactic integration costs (Kaan et al., 2000); or structure-building, checking, and diagnosis, with a latency that depends on the time required to identify and activate elements for these operations (Phillips et al., 2005). Topographic and latency differences, however, suggest there might be a family of P600s with different distributions (frontal, parietal), latencies (early, late) and functional significances (syntactic integration, syntactic repair, and reanalysis), though the details remain controversial (Hagoort and Brown, 2000; Friederici et al., 2001; 2002; Kaan and Swaab, 2003; Carreiras et al., 2004).

Alternatively, it has been suggested that the P600 is a domain-general (not language-specific) response. This conclusion is based on observations of positivities similar to the P600 in appearance, latency, and scalp distribution but elicited by non-syntactic violations within language, such as of orthography (misspelt words; Münte, Heinze et al., 1998) and lexico-semantics post-N400, as well by various non-linguistic violations such as those in music (harmonic and melodic; Besson and Macar, 1987; Janata, 1995), geometric forms (Besson and Macar, 1987), abstract sequences (Lelekov et al., 2000), and arithmetic sequences (Nieddeggen and Rösler, 1999; Nunez-Pena and Honrubbia-Serrano, 2004). These non-linguistic P600s are also similarly modulated by the difficulty of integrating the eliciting item into context. Patel et al. (1998) thus proposed that the P600 reflects a general index of violation in any rule-governed sequence. As P600 amplitude to syntactic violations has been found to vary with the proportion of experimental sentences that are syntactically ill-formed (when well-formedness is infrequent, it is the grammatical event that elicits the P600 instead), as well as with attentional manipulations, another domain-general hypothesis equates the P600 with the P3b (Coulson et al., 1998a; 1998b). The P3b is considered a general-purpose response to low probability events often associated with categorization and/or a binary decision, which on one account reflects working memory updating (Donchin and Coles, 1988; Kok, 2001).

A definitive conclusion about the equivalence (or even non-trivial resemblance) between P600s following syntactic violations and the positivities to non-syntactic violations and/or to the P3b cannot be reached without knowledge of their neural generators. The P600 may nonetheless be useful for investigating language-processing problems that are syntactic in nature—at least under well-defined conditions, given that at present no one can predict with certainty whether a P600 (or N400) will be elicited under novel experimental conditions. There are several recent reports of P600 effects together with either a small or no N400 in response to verbs that the authors believed should elicit N400s rather than P600s; e.g. *eat* in *At breakfast, the eggs would eat every day* (Kuperberg et al., 2003) elicited a small N400 together with a moderate-sized P600; *vluchten* in *De muizen die voor de kat vluchtten renden door de kamer*/ 'The cat that *fled* from the mice ran across the room' elicited a P600 (Kolk et al., 2003; van Herten et al., 2005); *geworpen* ending the Dutch sentence *De speer heft de atleten geworpen*/ "The javelin has by the athletes *thrown*" elicited a P600 (Hoeks et al., 2004), as did *devouring* in *The meal was devouring* (Kim and Osterhout, 2005). On the basis of such results, van Herten et al. (2005) suggested that the P600 reflects monitoring for the veridicality of unexpected linguistic events, though it could also reflect the momentary call for attentional resources by a well-practiced process running largely outside the focus of attention.

An intermediate domain-specific (but non-modular) account of syntax-related ERP components can be found in the Unification Model (Hagoort, 2003a, based on Vosse and Kempen, 2000). This is a lexicalist parsing model in which all syntactic information is stored and retrieved from the mental lexicon, with the only grammatical rule being to "unite" words (each a three-tiered structure of root node, functional node, and foot node). On this model, LAN activity reflects a binding failure whenever there are no two lexical items in the unification space for which a foot node of one matches the category of a root node of another, or a category match is accompanied by an egregious mismatch in grammatical feature specifications. The P600 reflects the ongoing process of establishing unification links with an amplitude determined by the degree of competition among alternative unification options, modulated by syntactic ambiguity, syntactic complexity, and semantic/pragmatics constraints.

23.4.2 **Parsing**

As for other aspects of language processing, determining the underlying syntactic structure of a sentence (sentence parsing) is rendered difficult by ever-present ambiguities. For example, consider a sentence such as *David told the girl that*, in which the role of *that* is temporarily lexically and syntactically uncertain; it could be a complementizer signaling a complement clause continuation (*David told the girl that there would be guests for dinner*), or a relative pronoun signaling a relative clause continuation (*David told the girl that had been on the phone to hang up*). Although the parser could theoretically adopt a "wait and see" approach to such ambiguities, as previously discussed, evidence suggests instead that comprehension proceeds incrementally, with readers and listeners attempting to integrate each word into a continually evolving message-level interpretation. There may be a cost to this incremental approach: adopting the wrong analysis initially can cause processing difficulties downstream such that a comprehender is "garden-pathed," e.g. at *had*, if *that* was initially taken to be a complementizer.

A number of different types of models have been put forward to explain how the language system deals with temporary ambiguities of this kind. These models differ along a number of dimensions, including whether non-syntactic information can affect the parse and whether the parser is restricted to choosing a single analysis or considers multiple possible parses at the same time. Extensive empirical work, using both behavioral and eye tracking measures, has been dedicating to adjudicating between these different accounts (see Altmann, 1998).

Brown, Hagoort, and van Berkum (Van Berkum et al., 1999; Brown et al., 2000; Van Berkum et al., 2003), for example, examined the ERP effects of discourse-semantic constraints and lexical-syntactic (grammatical gender) constraints on each other and on on-line parsing in mini-stories that ended with a sentence containing a temporary complement/relative clause ambiguity:

[Two][One]-referent discourse contexts:
David had told *[the boy and the girlNEU]/[the two girlsNEU]* to clean up their room before lunch time. But the boy had stayed in bed all morning, and the girl had been on the phone all the time.

Target sentence with sentential complement:
David vertelde het meisje *dat er* visite kwam
David told the girlNEU *that there* would be some visitors.

Target sentence with relative clause:
David vertelde het meisje *dat had* zitten bellen op te hangen.
David told the *girlNEU thatRELPR(NEU) had* been phoning to hang up.

In Dutch, where the complement clause interpretation is preferred over the relative clause interpretation in the absence of any additional information, the processing cost of being garden-pathed is evidenced in both written and spoken sentences in a P600 to *had*, which signals the less preferred, relative-clause continuation. This default complement-clause preference is overridden on-line by discourse: the availability of two potential referents for the target noun (*the girl*) biases for a relative clause reading as indexed by a P600 to *er* (*there*) introducing the sentential complement in the two-referent relative to one-referent discourse. However, the presence of a unique referent biases for a sentential complement reading, as indexed by a P600 to *had*, which disambiguates for a relative clause reading in the one-referent relative to two-referent discourse (Van Berkum et al., 1999; 2003; Brown et al., 2000). These data are clearly at odds with syntax-first theories that deny the parser any pre-parse access to discourse information (Frazier and Rayner, 1982), being more consistent with context-sensitive theories that allow the parser immediate use of discourse information (Altmann, 1998; Spivey and Tanenhaus, 1998).

In Dutch, it is only following neuter-gender nouns (such as "girl") that *dat* gives rise to a complement/relative clause ambiguity; following a common-gender noun (such as "woman") *dat* is unambiguously a complementizer (a relative clause reading would be signaled by *die*, "it"). Nonetheless, in both written and spoken sentences, a P600 is elicited by *dat* in the two-referent discourse even when the preceding noun is of common gender. Thus, even though the syntactic agreement rules of Dutch preclude a relative-pronoun reading due to the grammatical gender of the immediately preceding noun, the parser nonetheless seems to pursue a relative clause analysis. Taken together, these findings support language comprehension architectures that not only allow interaction between discourse-semantic, syntactic, and lexical levels, but wherein discourse can rapidly affect syntactic analysis (at least in the presence of structural ambiguity— though see Osterhout et al., 2004 for similar conclusions regarding unambiguous sentences).

23.5 **Slow potentials and the CPS**

Potentials like the P600, LAN, and N400 are observed by time-locking to the onset of a word (in an auditory stream or during word-by-word reading), and are taken to reflect processing that unfolds in response to that word (in relation to its context). However, this is only one of several critical time-scales for both neural processing and language processing, which unfold at time levels ranging from sub-milliseconds (e.g. an action potential and/or the duration between action potentials) to seconds and minutes (e.g. the unfolding of a sentence or discourse) and hours and even days and years (e.g. the consolidation of memory). Processes taking place over different time-scales differ intrinsically from one another: faster and slower processing typically underlie different types of operations, take place in different brain areas, and even possibly are carried out by different neural mechanisms. In ERP studies, for example, the response to sentences is not predictable from that to individual words; rather, responses to individual words in sentences ride on top of slower responses that develop over phrases, clauses, and sentences. For example, several studies have reported slow anterior negative potentials—for both auditory and visual sentence presentation—that often vary with working memory load, induced by syntactic, referential, or conceptual complexity and/or ambiguity (see Figure 23.3). Prolonged frontal negativities were initially described for a comparison of object vs. subject relative sentences in English, starting at *who* and spanning the course of the sentence (e.g. *The fireman who the cop speedily rescued sued the city over working conditions* vs. *The firemen who speedily rescued the cop sued the city over working conditions*); these were related to holding a displaced item in working memory pending its assignment to its usual position in a long distance (filler-gap) dependency (King and Kutas, 1995; Kutas and King, 1996; Müller et al., 1997). Similar patterns are seen with *wh*-movement in *wh*-questions (Kluender and Münte, 1998; Fiebach et al., 2001) and in response to clause-internal scrambling in German (Rösler et al., 1998). Ueno and Kluender (2003) likewise observed a prolonged frontal (bilateral) negativity in Japanese, spanning a displaced element and its canonical word position in so-called "scrambled" sentences in which word order, though legal, was non-canonical; (O–S–V) vs. canonical (S–O–V) sentences. By some accounts, "scrambling" creates a filler-gap dependency. Sentences in which events are described in reverse chronological order (*Before the psychologist submitted the article, the journal changed its policy*) also elicit a frontal negativity, beginning ~300 ms after first-word onset, that grows progressively across the sentence, compared to sentences with events described in chronological order of occurrence (*After the psychologist submitted the article, the journal*

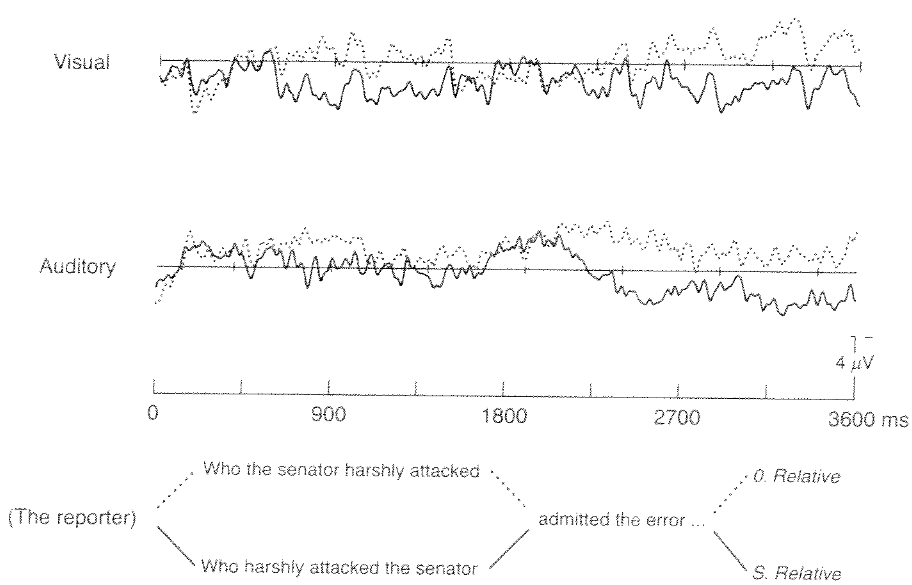

Figure 23.3 Comparison of grand average sentence-level ERPs for subject-relative vs. object-relative sentences at a site approximately over Broca's area for written sentences presented one word at a time (data from King and Kutas, 1995) and for naturally spoken sentences (data from Müller et al., 1997).

changed its policy); the amplitude of this effect is highly correlated with working memory capacity (Münte, Schilz, and Kuta, 1998). As differences in phrase structure analyses cannot be the origin of the processing problem in such sentences, Ueno and Kluender (2003) hypothesized that perhaps all processing difficulties associated with moved constituents, including filler-gap dependencies, index deviations from the preferred canonical word order, partly based on statistical frequencies of occurrence and perhaps on a general preference for canonicity in language. Finally, within the language domain, a sustained frontal negativity (just slightly longer than a typical LAN) was seen starting ~300 ms after the onset of the definite noun target in the mini-stories, described above, when the discourse had previously provided two as opposed to only one possible referent (Van Berkum et al., 1999; 2003).

Slow potentials with similar morphologies (though variable latencies and topographies as functions of type, modality, and amount of material) also have been observed in various verbal and non-verbal memory tasks accompanying information maintenance in working memory as well as episodic retrieval (Rösler et al., 1993; Donaldson and Rugg, 1999). Given their similar morphologies and sensitivities to comprehension skill or working memory load, it may be more parsimonious to associate all the slow negativities with some aspect of (working) memory processes than with linguistic processing (structural or referential) per se. Slow potentials over left frontal sites have been linked to verbal rehearsal, since in retention tasks their amplitudes co-vary with memory load, accuracy, and speech rate (Ruchkin et al., 1994; Ruchkin et al., 1999), as well as with the controlled attentional processes of maintenance, focusing, and shifting of attention (Bosch et al., 2001). Their specificity to language notwithstanding, the existence of over clause and sentence potentials that are not simple sums of their constituent transient word ERPs makes it difficult to study subprocesses in isolation with the hope of straightforwardly "scaling up" to other levels of analysis.

Modality of input is also likely to be an important factor for understanding the neural bases of language. Sentence-processing theories rarely mention whether a sentence is written or spoken, presumably because modality has little bearing on mechanisms beyond word recognition. Amplitude and timing differences across the scalp notwithstanding, many of the ERP effects discussed thus far (N400, LAN, P600, slow negativities) present with similar functional characteristics in all modalities, suggesting non-trivial similarities in neural processing. Indeed, it is in part the modality-independence of the brain response that allows the linking of components to modality-non-specific constructs. Such results have additionally been important for showing that the observed ERP patterns are not spuriously induced by the artificiality or relative slowness (on the slower end of language processing rates) of the often-used word-by-word visual presentation format.

Of course, the extent to which sentence processing is amodal in nature is an empirical question that necessitates systematic investigation for each of the hypothesized mechanisms, one by one. While evidence suggests that at least some people may "hear" words as they read them, evidence is scant on whether our "inner voices" mimic the prosodic patterns (sentence accents, intonational phrasing) of spoken language. However, a few theorists have hypothesized a phonological level of representation that impacts syntactic analysis during reading, and have suggested that punctuation (e.g. commas) might be viewed as an orthographic equivalent of prosody in speech. On this proposal, the same way that a prosodic boundary after *jogs* in (*Since Jay always jogs__a mile and a half seems like a very short distance to him*) diminishes the garden-path effect resulting from the parser's preference to interpret the ambiguous noun phrase (*a mile and a half*) as the object of the preceding verb (*jogs*) rather than the subject of the upcoming verb (seems), a comma after *jogs* would prevent the usual misleading parsing preference.

Steinhauer and Friederici (2001) reasoned that if punctuation is mediated by covert prosody, then its processing should resemble that of covert prosody. And, indeed, a centro-parietal positivity (closure positive shift, CPS) is elicited whenever a comprehender perceives a prosodic boundary, even in delexicalized speech (filtered so that only prosodic contour, and not segmental information, remains), jabberwocky, pseudowords, and hummed speech (Steinhauer et al., 1999; Pannekamp et al., 2005). Commas in written text also elicit a CPS, at least in individuals who appreciate the appropriate use of commas, suggesting that commas may covertly trigger prosodic phrase markings and determine initial parsing of sentences via the same mechanisms as speech boundaries. Prosody may also serve syntactic prediction (Isel et al., 2005).

23.6 Plasticity and learning

This review has focused on visual and auditory sentence processing in the average adult. We would, however, be remiss not to point out that as a direct measure of brain activity, ERPs also can inform us about both developmental and adult plasticity in language learning (see Neville and Bavelier, 1998). ERP studies with normal infants and children during language acquisition point to continual developmental changes in the configuration of language-related brain systems (including a crucial role for the right hemisphere), with differential sensitivity of different language subsystems to age and experience (Mills et al., 1997). Experience-based plasticity for language is also evident in ERP investigations in congenitally deaf adults who are native signers (compared with non-native deaf signers and normally hearing signing and non-signing adults), as well as in adults following brain damage leading to some form of aphasia, with some evidence in both for short- or longer-term recruitment of the right hemisphere (Altenmüller et al., 1997). Perhaps most surprisingly, ERP data attest to long-term plasticity in adult brains learning a second language. In one experiment, for example, ERPs to semantic and syntactic violations in sentences were examined at one month, four months, and eight months of instruction. For the fast language learners, semantic violations elicited almost native-like N400 amplitudes after only one month of instruction, whereas article–noun number agreement violations did not elicit any notable differential ERPs even after eight months, and violations of verb conjugation rules elicited an N400-like effect at one month but a P600 after eight months (reviewed in Osterhout et al., 2004), mirroring the earlier development of semantic than syntactic processing in children (Hahne et al., 2004). Tokowicz and MacWhinney (2005) found P600s only to syntactic violations similarly formed in participants' first and second language, and not for syntactic constructions specific to the second language. These results with second-language learners reinforce the obvious but often-forgotten point that it is how brains actually process stimuli, rather than the labels experimenters assign to manipulations, that determines the ERP elicited.

23.7 Conclusions

Electrophysiological researchers have described a wide array of brain processes that are sensitive to linguistic variables, though so far none is indisputably language-specific. It seems, then, that language processing in the human brain is built of the same sensory-perceptual, attentional, working and long-term memory, mapping, and integrative mechanisms, and is subject to the same principles as information processing as in other cognitive domains. Intracranial and scalp-recorded ERPs implicate many brain areas in language processing and implicate qualitatively different contributions from the two hemispheres—though how the information flow is orchestrated within, much less across the two hemispheres, remains a fascinating mystery.

In sum, the model of language processing emerging from ERP research (bolstered by studies using eye-tracking and behavioral measures) is one of a highly flexible, error-tolerant system in which lower- and higher-order representations are built moment by moment, necessitating provisional, probabilistic choices to deal with uncertainty and ambiguity along the way. These choices are influenced by information at multiple levels—lexical, sentential, discourse-referential—all potentially available at about the same time, and operating approximately parallel and with the potential for considerable interactivity (see also Hagoort, 2003a; though see Friederici, 2002 for a different conclusion). Moreover, these choices seem to entail the allocation of neural resources of various kinds to varying degrees depending upon the nature of the language input, the conceptual operations needed to construct its meaning, and the comprehender's speed of neural processing, capacity for short-term storage and processing, background knowledge-base, and developmental and learning-based experience with the language. This perhaps explains why, for example, so many different patterns of timing and relationship between syntax and semantics have been reported (Van Berkum et al., 1999; Hahne and Jescheniak, 2001; Hagoort, 2003b; Van Berkum et al., 2003; Vos and Friederici, 2003; Friederici et al., 2004; Frisch et al., 2004; van den Brink and Hagoort, 2004; Kim and Osterhout, 2005).

Finally, we think that ERPs most directly show that the accumulating information (from sensory input and semantic memory combined) seems not only to passively shape the immediate processing environment but also to provide the basis for active preparations made in anticipation of likely upcoming perceptual, grammatical, phonological, and semantic features, concepts, and words. ERPs thus afford psycho(neuro)linguists multiple glimpses into the time-course and nature of comprehenders' on-line understanding of the unfolding sentence or narrative—literal or non-literal—and the various representations and processes involved, as well as their language-processor's probabilistic guesses about the words, structures, and concepts yet to come.

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