24 Language

MARTA KUTAS, KARA D. FEDERMEIER, JENNY STAAB, AND ROBERT KLUENDER

The Brain – is wider than the sky –
For – put them side by side –
The one the other will contain –
With ease and you beside

The Brain is deeper than the sea –
For – hold them – Blue to Blue –
The one the other will absorb –
As Sponges – Buckets – do

The Brain is just the weight of God –
For – Heft them – Pound for Pound –
And they will differ – if they do –
As Syllable from Sound

– Emily Dickinson, 1896

1. HISTORICAL CONTEXT

As Dickinson notes, the brain has a remarkable capacity that differentiates it from other sorts of material substances: the ability to intentionally represent, to impose its own internal order on perceptions of the outside world supplied to it via the senses. Although we often take this capacity for granted, it is no small feat that we are able to access, decipher, and interpret the thoughts of a woman who died well over a century ago. While many consider Dickinson to be an exceptionally gifted poet, her ability to exploit the representational capacity afforded by the brain through language is shared by all humans. This capacity allows us to analyze our own internal thought processes, to communicate with one another across distances of time and space, and to alter our environment by influencing one another's behavior.

It is this ability that intrigues language researchers and inspires them to plumb the depths of the language system in hopes of unmasking its intrinsic principles and underlying mechanisms. With the onset roughly half a century ago of the cognitive revolution, language quickly came into focus as one of the main puzzles of human cognition. The most fundamental reason for this puzzlement is that, at least *prima facie*, language is a behavioral phenomenon not found in any species other than our own. Moreover, language mediates virtually every aspect of human social and cultural interaction. Human beings are the only species in which language plays a role not just in the formation of mental representations, but in the interrelationships of such representations with each other and with the external environment as well. By understanding language, we thus not only gain a privileged window into the internal workings of the human mind, but also a way to comprehend how it relates to the outside world.

At this point in history, we already know something of the intrinsic principles and mechanisms of language. For example, we know that language is a multi-layered system, with principles that apply at different levels of organization, namely those of sound (phonetics and phonology), the word (morphology), the phrase and the sentence (syntax), the entire text, be it written or spoken (discourse and information structure), and meaning (semantics and pragmatics) – cf. section 3. We further know that because language is a serialized signal that unfolds sequentially in time and space, it must rely on the support of other cognitive systems, including attention and memory, both working and long-term.

Long-term memory provides a useful illustration of the difference between principles and mechanisms of language and between the often complementary interests of linguists and psycholinguists. Long-term memory plays an important role in the pairing of sound patterns with associated meanings at the level of individual lexical items, which must be accessed and retrieved during on-line processing. This process of "lexical access" is a major focus of investigation with respect to both psychological and neural mechanisms (see section 4). However, it is largely absent from purely linguistic discussions because, among the linguist's inventory of ontological primitives, the word is the most poorly defined. Even though linguists know a great deal about the principles governing word formation (morphology), they merely assume that words are taken from the lexicon when inserted into syntactic structures, as the mechanism(s) of lexical insertion remains largely unspecified.

More generally, the ontological status of linguistic principles, levels of organization, and mechanisms lies at the heart of three related but logically independent debates within linguistics and psycholinguistics, commonly referred to as competence versus performance, modularity, and psychological reality. With regard to the first, Chomsky (1965) has taken great pains to distinguish a language user's inherent knowledge of his or her native language (competence) from its implementation in real time and space (performance). The former is an abstract, idealized, almost Platonic set of mental representations distributed across a speech or sign community, whereas the latter is an imperfect individual reflection of this, subject to human cognitive limitations on attention and memory, etc. The prevailing view within linguistics for the past half century has been that competence rather than performance is the proper subject of the language researcher's investigation. This is because competence remains relatively stable over time – though subject to changes across generations as innovations make their way into the system – whereas performance is subject to the moment-to-moment vagaries of on-line processing. This is another reason why linguists have traditionally paid little attention to the mechanics of processes like lexical access: everyone is familiar with the effects of impaired memory on lexical access in the individual brain, but this has no impact whatsoever on the collective repository of lexical items in any given language.

However, while many linguists still adhere to a strict dichotomy between competence and performance, others have begun to challenge it: in recent years, performance-based accounts of a number of core linguistic facts usually attributed to competence – such as basic word order (Hawkins, 1994), and dependencies between discontinuous sentence elements, so-called "unbounded dependencies" (Hawkins, 1999; Kluender, 1998, 2005) – have emerged. During this same time period, a number of event-related brain potential (ERP), positron emission tomography (PET), and functional magnetic resonance imaging (fMRI) studies have investigated the precise role of working memory in the processing of unbounded dependencies (see section 4.3.2.1). The aim of these studies has been to determine whether syntactic mechanisms play a role over and above that of working memory in the processing of such structures, or whether the two are largely coextensive.

The second debate centers around Fodor's (1983) claim that cognition is the result of a large number of autonomously functioning, highly specialized input modules feeding into a more general-purpose central processor. The role of input modules is to transform specific inputs from the sensory periphery into representations that can be handled by this central processor. Since an input system is dedicated to processing only one type of input, it is said to be "informationally encapsulated," i.e., insensitive to any source of information that falls outside its particular domain of specialization. It is also argued that the central processor has access only to the outputs of such modules and not to any intermediate representations that they may compute for their own internal purposes. Perhaps most importantly for present purposes, each input module is said to be associated with a fixed neural architecture.

This series of claims has had two major consequences for the study of language. First, language itself is taken to be a sort of macro-module, independent of other cognitive systems like attention and memory; this is essentially a reification of the competence/performance distinction. Second, levels of organization within the language system are often taken to be sub-modules that are informationally encapsulated from each other. This claim has been made most frequently with respect to lexical and syntactic levels of processing, which are argued to be impervious, during lexical access and initial syntactic parsing operations, to semantic and pragmatic factors, in turn argued to engage higher-level processes of interpretation solely under the purview of the central processor. On this view, contextual meaning should not initially influence how a word is identified by the lexical access module or how a string is parsed by the syntactic module. Lexical access and syntactic parsing operations are thus expected to be subserved by brain regions different from those that figure in semantic or pragmatic interpretation.

Psychophysiologically, this expectation has been investigated most thoroughly with respect to comparisons and interactions of syntactic and semantic processing (see section 4.3.2.2.2), although it is not always obvious how to isolate syntactic processing from the influence of other levels of organization. For example, a common experimental manipulation compares active and passive versions of the same sentence, the general assumption being that the two versions differ in syntactic structure alone. However, passivization affects not only the alignment of semantic (or "thematic"; cf. section 3) roles with syntactic positions (either agent or undergoer (patient) as subject of the sentence in active vs. passive sentences, respectively), but also the underlying information structure of the sentence. To illustrate, the "team of authors" is not only the subject, but also the topic of the active sentence *A team of authors wrote the chapter*, while "the chapter" forms part of the informational focus, or new information about the topic. These information structural statuses are reversed in the passive sentence *The chapter was written by a team of authors*, in which "the chapter" is the topic and the "team of authors" is part of the new informational focus. Linguists are not sure whether to assimilate information structure to syntactic or semantic levels of representation or to consider it a completely independent level of representation on its own, although it is recognized to play a role in sentence structure over and above purely syntactic considerations.

Information structure is not the only level of linguistic organization for which it is difficult to entertain claims of modularity. As mentioned above, processes of word formation are quite well understood by linguists, but the notion that morphology should constitute an independent, autonomous, informationally encapsulated level of organization (and/or processing) within the language system is almost certainly wrong. Morphological processes of word formation are known to interact extensively both with "lower" level phonological processes, as well as with "higher" level syntactic processes; for this reason, linguists refer to – and distinguish between – "morphophonological" and "morphosyntactic" processes. Phonological processes similarly play a role in both morphology and syntax; aside from the subdiscipline of morphophonology just mentioned, a very popular topic in psycholinguistics at the time of writing is the role that prosody plays in word segmentation and in syntactic parsing. It is even difficult to see how morphology could be entirely dissociated from semantics, as affixes typically involve a concomitant change in word meaning: *lion* vs. *lioness*, *child* vs. *children*, *rational* vs. *irrational*, *write* vs. *rewrite*.

Nevertheless, there is a long-standing controversy within morphology itself that does bear on issues of modularity: the difference between regular (rule-based) and irregular (more or less idiosyncratic) processes of word formation. Note that here the claim for modularity is based on a sub-sub-module of the language system. The controversy centers around whether regular and irregular processes of word formation constitute separate subsystems, each with unique principles and mechanisms (the "dual route" model), or whether these two processes share the same resources (the "single route" model). There is an extensive behavioral and computational literature devoted to this topic, and there have been a number of psychophysiological studies as well (section 4.2.1).

The third debate in linguistics is referred to as psychological reality: is there any evidence to be found for the levels of organization posited by linguists, and the principles claimed to apply to them, in the on-line processing of language, or are they merely explanatorily convenient, abstract constructs? First raised by Sapir (1933), nowadays this issue is generally cast more in terms of finding behavioral evidence for linguistic constructs, and thus has been rejected by some as irrelevant to issues of competence (Chomsky, 1980). Nonetheless, the current prevalent trend in linguistic departments in the United States is to add positions in psycho- and neurolinguistics, pointing to at least tacit recognition of the fact that linguistic theory construction in the 21st century requires a broader empirical base that also addresses questions of psychological reality.

To this end, research on the psychophysiology of language processing – using techniques such as ERPs, PET, and fMRI – has attempted to monitor how the brain reacts to experimental manipulations at various levels of linguistic organization. As noted above, the assumption is that language subprocesses are subserved by different anatomical and physiological substrates that generate distinct patterns of biological activity – and this assumption is neutral with respect to issues of competence vs. performance, modularity, and psychological reality. These patterns of biological activity can then be picked up by methods sensitive to fluctuations in electromagnetic and hemodynamic activity.

Psychophysiological studies of language processing are well-suited to examine issues of both representation and processing. Techniques with high spatial resolution, such as PET and fMRI, can help pinpoint brain areas important for language processing. Techniques with high temporal resolution, such as ERPs and eye-tracking, can help reveal how language processing unfolds over time; they can be used to track the availability of different sorts of linguistic information and the temporal course of their interactions. Additionally, studies of brain-damaged patients, in conjunction with the use of psychophysiological measures, can provide important insights about which brain areas are necessary and/or sufficient for certain types of linguistic processes, and about the relationship between language processing and other cognitive abilities. In this chapter, then, we consider the role of the brain in understanding and producing natural language utterances. We review how psychophysiologists have addressed this issue in the past and consider how these methods might best be employed in the future.

2. PHYSICAL CONTEXT

The physical context for language is the human brain – the only known physical system capable of language. And, although some parts of the brain have been more closely tied to language than others, nearly the whole brain seems to be involved to some extent. Language comprehension, for example, depends on subcortical and cortical neural systems that transduce, process, and identify the sensory information that constitutes language input. Language production, in turn, ultimately makes use of the motor cortical, basal ganglia, and cerebellar systems that enervate the muscles and coordinate the movements of the diaphragm, intercostal muscles, vocal folds, jaw, tongue, and lips (and/or arms, hands, and face). Both comprehension and production require that information be attended, held in working memory, and accessed from long-term memory, thereby involving hippocampal, medial temporal, frontal and parietal areas. These brain areas show varying degrees of specialization for various linguistic processes, and many appear to perform general functions – like sequencing or mapping between inputs/outputs and knowledge – that are necessary for language without being unique to it.

Of course, some parts of the brain are considered by most neuroscientists to be particularly concerned with the processing of language. One of these is an area of left frontal cortex (Brodmann's area, or BA 44 and 45) known as Broca's area, damage to which (often including underlying subcortical tissue and white matter) causes an aphasia characterized by halting, "telegraphic" speech (lacking in function words) but with reasonably good comprehension. Despite its obvious import in language production and the control of articulation, there has been some controversy over whether the apraxia of speech is due to malfunction of Broca's area (Hillis et al., 2004) or the underlying insula (Dronkers, 1996; Ackermann & Riecker, 2004). Whatever its precise role, there is ample evidence not only for its involvement in language processing but for functional subdivisions of this area (see Bookheimer, 2002).

For example, imaging studies have found activation in posterior aspects of the left frontal operculum (especially BA 44) associated with phonological encoding in production (see meta-analysis by Indefrey & Levelt, 2004) as well as with phoneme discrimination (Zatorre et al., 1996) and sequencing (Demonet et al., 1994) during comprehension. Some have suggested that the primary role of this area is to subserve articulatory-based working memory processes (Hickok & Poeppel, 2004). Similar arguments have been made for the role of the more medial portion of Broca's area in syntax. Lesions to Broca's area cause problems with the production (Friedman & Grodzinsky, 1997) and interpretation (Grodzinsky, 2000) of syntactically complex sentences, and this area has shown activation in many imaging studies comparing relatively simple to more complex syntactic structures (see 4.3.2.1). While some have taken this to mean that syntactic processing is mediated by Broca's area (e.g., Grodzinsky, 2000), others have suggested that it subserves general or syntax-specific aspects of working memory (Caplan & Waters, 1999; Caplan & Waters, 1999; Fiebach, Schlesewsky, & Friederici, 2001; Kaan and Swaab, 2002; Friederici, 2002).

Finally, anterior portions of Broca's area (BA 47, and the inferior part of BA 45) have been linked to semantic processing (reviewed in Bookheimer, 2002; Gabrieli, Poldrack, & Desmond, 1998). Thompson-Schill and colleagues have argued that this area is not specific to semantics but rather is involved in selection more generally, showing increased activation when competing, irrelevant information engenders high selection demands (1999; Kan & Thompson-Schill, 2004) and deficits in selection when damaged (Thompson-Schill et al., 1998). Others, however, have suggested that it is a more superior and posterior area that mediates selection (Martin & Chao, 2001; Wagner et al., 2001), linking the anterior portion of Broca's area with controlled semantic retrieval.

The functionally specific sub-areas that seem to make up the original "Broca's area" have thus been linked to language at the sound, structure, and meaning levels, especially for production but, to some extent, also for comprehension. What remains more controversial is whether the computations this brain area performs are language-specific or more general. Both lesion and imaging work suggest that Broca's area is especially critical for language functions, yet activity in this area has also been observed during non-linguistic tasks such as tone discrimination (Müller & Basho, 2004), motor imagery (Binkofski et al., 2000; Hanakawa et al., 2003), and imitation (Iacoboni et al., 1999; Leslie, Johnson-Frey, & Grafton, 2004), consistent with its being part of more general brain systems concerned with segmentation, planning, working memory, and/or selection processes, among others.

Another brain area closely linked to language is Wernicke's area (BA 22) in the left temporal/parietal cortex. Damage to this area produces a "fluent" aphasia and impaired comprehension; patients' speech has normal rate and rhythm together with many paraphasias (incorrect word substitutions) that render it nearly incomprehensible. Wernicke's area has traditionally been associated with language comprehension and semantics, though it too has been subdivided into functionally specific subareas.

The traditional "Wernicke's area," the posterior superior temporal gyrus (STG), has become closely linked to phonological decoding. Lesions to this area cause word deafness (especially, or even perhaps only, when bilateral: Poeppel, 2001; Buchman et al., 1986), and bilateral STG activation is consistently observed in speech comprehension tasks (Hickok & Poeppel, 2000, 2004). This area is also sensitive to the acoustic properties of speech (Binder et al., 2000; Scott et al., 2000), although left and right STG may mediate somewhat different aspects of acoustic processing (Ivry & Robertson, 1998). The left posterior STG seems to play a more crucial role for language *production*, as damage to this area causes a conduction aphasia marked by phonemic production difficulties at all levels (Anderson et al., 1999; Boatman, 2004). The anterior portion of the STG is also important for the analysis of speech (Scott & Wise, 2004), but it seems to play an additional role in the processing of language structure. Lesions to this portion of the STG are associated with syntactic processing deficits (Friederici, 2002; Dronkers et al., 2004), and imaging studies find increased activation in this area for sentences versus word lists (Stowe et al., 1999), for ungrammatical versus grammatical sentences (Meyer et al., 2002), as well as activation changes linked to syntactic priming (Noppeney & Price, 2004).

More inferior parts of the temporal lobe have come to be associated with processing at the interface between sound and meaning. Damage to the posterior portion of the middle temporal gyrus (MTG) has been associated with severe word comprehension and naming deficits (Dronkers et al., 2004). Activations in this area have been observed during word comprehension (Binder et al., 1997) and the processing of environmental sounds (Lewis et al., 2004), as well as in a meta-analysis of production imaging studies, where it has been linked to "conceptually driven lexical retrieval" (Levelt & Indefrey, 2004). Still more inferior areas, in the inferior temporal gyrus (ITG) and fusiform gyrus, seem to play a role in reading, naming, and concept retrieval. Stimulation of this "basal temporal language area" (in epileptic patients undergoing surgery) results in language deficits ranging from anomia to global expressive and receptive aphasias (Lüders et al., 1991). The fact that only transient aphasia results from damage to the basal temporal language area suggests that its functions are or can be duplicated by other brain areas (or, perhaps, that stimulation of this area disrupts language primarily through its connections with other language areas). Nevertheless, imaging studies suggest that activity in this area accompanies normal semantic-linguistic processing (Thompson-Schill et al., 1999; Chao, Haxby, & Martin, 1999). The "visual word form area" in the posterior fusiform is consistently activated in reading tasks (review in Cohen et al., 2002) and is sensitive to abstract orthographic properties (Polk & Farah, 2002). It has been hypothesized to be involved in the prelexical processing of letter strings, though it also becomes active in a variety of other (even non-visual) tasks (Price & Devlin, 2003).

The aforementioned brain areas classically associated with aphasia, and thus with language – Broca's area and Wernicke's area – are in the left cerebral hemisphere, leading to the now widely accepted view that the left hemisphere is the "verbal" hemisphere and the right is the "nonverbal hemisphere." However, it now seems that left-lateralization may be strong only for language production, with the right hemisphere playing a more important role in the integrative and pragmatic aspects of comprehension (for reviews see Joanette, Goulet, & Hannequin, 1990; Beeman & Chiarello, 1998). Right hemisphere damage has been associated with difficulties producing and comprehending both affective and linguistic prosody (Wymer, Lindman, & Booksh, 2002; Baum & Dwivedi, 2003) as well as with impairment in processing a variety of types of non-literal language, including indirect requests, sarcasm and speech acts (Kaplan et al., 1990; Champagne et al., 2003), connotations, jokes and humor. Right hemisphere damage has also been associated with more general problems drawing inferences and processing language at a discourse level. Correspondingly, imaging studies often observe bilateral – or even in some cases right-lateralized – activity in a variety of language tasks. For example, activity in right hemisphere homologues of left hemisphere language areas (inferior frontal gyrus, posterior superior temporal sulcus) has been seen in tasks requiring judgments of metaphorical meaning (Bottini et al., 1994), use of higher-level linguistic context (Kircher et al., 2001; St. George et al., 1999; Robertson et al., 2000), use of metalinguistic knowledge (Meyer, Friederici, & von Cramon, 2000), and monitoring of emotional prosody (Buchanan et al., 2000).

Overall, recent neuropsychological and imaging data suggest that a complex network of brain areas, including frontal, temporal, and parietal cortical areas in both hemispheres, along with associated subcortical structures, subserve normal language processing. A small set of these areas subserves functions that are so particular and so critical for language that damaging them causes severe and sometimes permanent language deficits. However, a larger set of areas also seems to make important contributions to language, albeit contributions whose loss can more readily be compensated for. As a result, the precise network involved in any given situation will depend heavily on the choice of experimental and control tasks and the methods used to process and analyze the data. When drawing conclusions from neuroimaging data, as from all types of psychophysiological data, it is thus important to recognize the inferential leaps required by and the inferential limitations inherent in mappings from physiology to psychology (see Chapter 1 and Sarter et al., 1996).

3. SOCIAL/COGNITIVE CONTEXT

For at least 100,000 years our species has used language to describe – and construct – the world around us. First, and perhaps most obviously, language provides a medium for the communication of thoughts via a structured stream of sound, or, in signed language, manual and facial gesture. Upon hearing or seeing language, comprehenders are somehow able to formulate a mental representation of the conceptual content of the spoken, written, or signed message, which can alter the comprehenders' mental state and affect subsequent behavior. Language thus provides the primary means of social interaction, enables the coordination of group action, and plays an organizing role in social relationships. Second, language enables us to transmit cultural knowledge such as customs and values.

The cognitive basis of this complex human skill involves representations and processes at a number of different levels, the regularities of which are investigated by subdisciplines within linguistics. Moving from sound to meaning, these disciplines include phonology, the study of linguistic sound patterns; morphology, the study of word formation; syntax, the study of hierarchical structure in individual utterances; information structure, the study of structure in spoken and written discourse; semantics, the study of context-invariant aspects of meaning; and pragmatics, the study of meaning in use. Although it is still unclear how traditional linguistic categories map onto brain structures and functions, it is important to consider the work of linguists as a relevant starting point for exploration of these issues.

Although our intuition may suggest that the fundamental unit of language is the word, linguistic research has shown that words are composed of more fundamental units known as phonemes and morphemes. Phonemes are categories of sounds considered equivalent to each other in a language and that distinguish one word from another: in *The cat sat on the mat*, the phonemes /k/, /s/, and /m/ recombine with the phonemes /æ/ and /t/ to form three different English words. Morphemes are the smallest units of meaning in a language: *cat* consists of three phonemes but only one morpheme, while *anti-dis-establish-ment-ari-an-ism* consists of seven morphemes, each contributing to the meaning of the word as a whole. This idea of building up meanings by combining representations at different levels is a recurrent one in linguistics because it helps explain the fact that we can express an infinite number of different meanings with a limited repertoire of speech sounds. Thus, phonemes are combined into morphemes, morphemes into lexemes (words), words into phrases, phrases into sentences, and sentences into discourses.

Just as words are built up out of individual sounds, sentences are built up from individual words. The relationship between words and sentences is complex and involves structure at a number of different levels. "Parsing" is the process of analyzing the input into a series of lexical units and mapping higher order structures onto those units in a consistent and eventually meaningful way.

Words are divided into "grammatical categories" (traditional parts of speech: noun, verb, etc.), and syntax is the study of the relations among them – grammatical, phrase structural, subcategorization, and thematic. "Grammatical relations" include the traditional parts of a sentence: subject, object, etc. Words combine to form phrases in hierarchical configurations ("phrase/tree structures") that encode grammatical relations. For example, the direct object of a verb is the noun phrase (NP) sister node of a verb (V); together, they form a verb phrase (VP). VP–> V NP is a "phrase structure rule." The entry of a word in the lexicon also specifies syntactic information. For example, not all verbs take direct objects: those that do are called transitive verbs, those that don't are intransitive. This distinction is captured in a verb's "subcategorization frame." Within the grammatical category of verbs, subcategories of verbs take different syntactic complementation options: the lexical entry of a transitive verb specifies that it takes an NP complement, while that of an intransitive verb specifies that it takes no complement at all. "Thematic relations" are also lexically specified, and they determine the types of semantic roles that a verb co-occurs with. Thus a transitive verb like *make* takes both an agent and a patient/undergoer, while an intransitive verb takes either an agent (as in *run*) or a patient/undergoer (as in *die*), but not both.

Psychophysiological techniques have been used to study language representations and processes at nearly all levels of analysis; the relevant methods, measures, and inferences will be reviewed briefly in the remainder of this chapter.

4. INFERENTIAL CONTEXT

4.1. What's the word?

From the brain's perspective, language is a mapping between physical inputs/outputs, in the form of written, spoken, or signed signals, and experiences, memories, and knowledge stored in long-term memory. One of the critical units for such mapping is the word. Psychophysiological methods have been aimed at better specifying the features of a word, the organization of different kinds of information associated with a word, and the various influences on word processing. One proposal is that information about words is represented in a mental "lexicon" containing both lower-level phonological and orthographic information, as well as higher-level information about a word's meaning and its various syntactic properties (when applicable), such as grammatical gender and subcategorization (though see Elman, 2004). On the standard model, recognizing a word activates this information in the lexicon, in a process known as "lexical access." This information, in turn, is used to combine the meanings of words into phrases and the meanings of phrases into sentences and discourses.

In this section we consider how, where, and when the brain is able to distinguish between sensory input that is treated as language and other sorts of perceptual information, ERP effects of local and global frequency, and the sensitivity of ERPs to lexical word class and word meaning.

4.1.1. Lexical versus perceptual processing of word forms

Initially, a linguistic stimulus is just another sensory signal – a pattern of light hitting the retina or a constellation of sound pressure waves reaching the cochlea. It is not surprising, therefore, that the earliest brain responses to language are indistinguishable from those to other types of visual and auditory inputs. Eventually, however, the brain begins to categorize (and thus respond differentially to) the input, for example, as a visual string rather than a single object, as a familiar event rather than a novel one, as belonging to the class of stimuli that may be associated with meaning, and so forth. When and how these classifications unfold are critical questions that have been partially answered by psychophysiological studies.

Schendan, Ganis, and Kutas (1998) examined the time course of visual classification by comparing the ERP responses to object-like, word-like, and intermediate stimuli. Regardless of task, around 95 ms a negativity over midline occipital sites distinguished the response to single object-like stimuli from those to strings, followed 10 ms later by a further distinction between strings composed of real letters and non-letters. Thus in the scalp-recorded ERP the first sign of specialized processing of "linguistic" stimuli appears around 105 ms. Results from intracranial recording and fMRI studies suggest that such differentiations may be occurring in the posterior fusiform gyrus (Allison et al., 1994) and the occipitotemporal and inferior occipital sulci (Puce et al., 1996). Finally, random letter strings are differentiated from pronounceable letter strings and words beginning approximately 200 ms post-stimulus-onset in the ERP. Spatial imaging studies have revealed activations that differentiate words and pronounceable pseudowords from non-words and false fonts in left medial extrastriate regions (Petersen & Fiez, 1993). Magnetoencephalographic responses likewise point to an important role for occipito-temporal cortex in reading within 200 ms, delineating a systematic sequence of activations from basic visual feature processing to object-level analysis (Tarkiainen, Cornelissen, & Salmelin, 2002; Cornelissen et al., 2003). Overall, these results intimate a hierarchy in which visual responses become increasingly selective for classes of visual stimuli over time.

A similar time-course of categorizations seems to hold for auditory inputs as well, with the first distinction between meaningful and nonsense words in the ERP around 200 ms (Novick, Lovrich, & Vaughan, 1985). PET findings suggest that activity early in primary auditory cortex and posterior temporal areas is unlikely to be language specific. In contrast, responses in and around Wernicke's area seem to be more specific for words, as well as for tasks exacting phonological processing such as judging whether two words rhyme (Liotti, Gay, & Fox, 1994). Across modalities and methods, therefore, observations support the idea that the processing of words diverges from that of other types of stimuli within about 200 milliseconds, and that this differentiation occurs in secondary perceptual processing areas of the brain.

4.1.2. Repetition, frequency, and neighborhood effects

Once words have been categorized as such by the perceptual system, other factors – such as a word's frequency in the language as well as within an experimental setting (repetition) – begin to affect their neural analysis (see Van Petten et al., 1991). The brain is sensitive to event repetition at many levels, reflecting its recent experience with a particular physical form as well as its recent activation of a particular feature, concept or meaning. For proper names, Pickering and Schweinberger (2003) observed font-sensitive repetition effects between 180–220 ms, font-insensitive repetition effects between 220–300 ms, and later same "person" repetition effects, whether accessed via the name or the face. Repetition reliably decreases N400 amplitude (a negativity between 300–500 ms) to words both within and between modalities, as well as to orthographically legal, pronounceable pseudowords, whether these are derived from (and thus closely resemble) real words or not. Thus, although the N400 is often associated with semantic processing (section 4.2.2), its amplitude can be modulated even when there is no specific meaning to be retrieved (Deacon et al., 2004). N400 repetition effects are largest for immediate repetitions and can be seen even in amnestic patients (Olichney et al., 2000). Finally, the N400 is often followed by a late positivity (LPC) that is also sensitive to repetition (Rugg, 1990).

The first reported effects of word frequency – that is, of the system's global experience with a particular linguistic stimulus – manifest around the time (~150 ms or so) that letter strings begin to be differentiated from words and pronounceable pseudowords. This stage of visual processing seems to be sensitive to orthographic regularity (larger P150 to words and pseudowords than to letter strings) and, more generally, to the amount of experience accrued for a given perceptual form (larger P150 to high than to low frequency words; Proverbio, Vecchi, & Zani, 2004). Then, between 200 and 400 ms, the latency of a left anterior negativity ("frequency sensitive negativity" or FSN), subsuming the N280, is sensitive to the eliciting word's frequency of occurrence in the language (King & Kutas, 1998; Osterhout, Bersick, & McKinnon, 1997; Münte et al., 2001). For words in list format, N400 amplitude is also an inverse function of a word's eliciting frequency with all other factors held constant (see Figure 24.1).

The processing of a particular word or word-like stimulus not only depends on how recently and how often it was experienced, but also on the system's experience with other, sufficiently similar, stimuli. "Lexical neighborhood density," which refers to the number of known words that differ from a given target by only a single letter (*N*-metric; Coltheart et al., 1977), also modulates N400 amplitudes: words and pseudowords with many lexical neighbors elicit larger amplitude N400s than those with fewer neighbors (Holcomb, Grainger, & O'Rourke, 2002).

4.1.3. Other lexical variables

During the 200–400 ms time range in which the ERP becomes sensitive to word frequency, effects of lexical class also appear – open class or content words, such as nouns, verbs, adjectives, and adverbs with significant semantic content, versus closed class or function words, such as articles, determiners, prepositions, and conjunctions with more relational content. FSN latency is sensitive to word frequency, irrespective of word class, though other negative components in this latency seem to be sensitive to lexical class *per se* (Brown, Hagoort, & ter Keurs, 1999; Münte et al., 2001). Content words elicit much larger N400s than function words, except when the latter is less expected than usual (King & Kutas, 1995); among function words, those with richer lexical semantic content elicit larger N400s than those with less (Kluender & Kutas, 1993a; McKinnon & Osterhout, 1996).

The ERP is also sensitive to further lexical subdivisions, such as that between nouns and verbs, showing both early and late differences in laterality, distribution, and sensitivity to potential and actual functional roles (Koenig & Lehmann, 1996; Khader et al., 2003; Federmeier et al., 2000). Within the category of nouns, those depicting a tangible, often pictureable, entity (concrete nouns) elicit larger N400s over frontal sites than do abstract nouns (Kounios & Holcomb, 1994), although less so within a supportive sentence context (Holcomb et al., 1999). The specific brain areas activated and reflected at the scalp seem to be influenced by the semantic content of words as well, differing for action versus perception related words, and within action verbs as a function of the body part involved (Pulvermüller, 2001).

4.2. Two of a kind: processing of word pairs

As previously noted, much language research has been aimed at determining the internal organization of the mental lexicon. To this end, a large number of studies have contrasted the responses to pairs of words (or other meaningful stimuli) that systematically vary along some dimension (orthography, phonology, morphology, semantics) as people make some decision about them. The pattern of sensitivity to types and degrees of similarity between the two stimuli – as well as interactions with task – have been used to address questions such as (among others): (1) what features constitute a lexical entry, (2) what resources and/or stages of processing are involved in the access and manipulation of various kinds of linguistic information, and (3) whether or not it makes sense to talk about an "amodal" representation of a concept that can be accessed via written, spoken, and signed words as well as via non-linguistic stimuli.

4.2.1. Orthographic, phonological and morphological relationships

As interfaces between the perceptual form of a word and its lexical and semantic properties, orthographic and phonological information are important components of most models of the lexicon. Several ERP studies have shown that the influences of these cues can be observed in the N400 time window and beyond. For example, in rhyme-judgment tasks, rhyming word pairs elicit a smaller negativity between 250–550 ms than do non-rhyming word pairs (Sanquist et al., 1980). When the rhyming pairs are orthographically dissimilar (*moose-juice*), reduced N400 amplitudes can be attributed to the phonemic similarity. However, when phonemic and orthographic similarity are crossed, Polich and colleagues (1983) found that both influence the amplitude of the N400, consistent with behavioral reports that orthography cannot be ignored during rhyme judgment. Rugg and Barrett (1987) further demonstrated that orthographic, and not just visual, similarity modulates N400 amplitude. However, the nature of the task seems to affect the expression of these effects: whereas semantic similarity effects obtain even under passive viewing conditions (more below), Perrin and Garcia-Larrea (2003) found that phonological similarity affected the N400 only when participants were making active judgments about the stimuli (though phonological effects on the N400 can be observed when the judgment itself is not about phonology; Liu, Perfetti, & Hart, 2003).

Morphological influences on word processing also have been observed in the ERP by around 250 ms. Morphological processing involves both the derivation of new words ("derivational morphology") and the marking of case, number, tense, and other word features ("inflectional morphology"). Several studies suggest that language users rapidly decompose words into their morphological constituents. McKinnon, Mark, & Osterhout (2003) observed larger N400s for pseudowords without morphemes (*flermuf*) compared to both real words and pseudowords with morphemes, suggesting that word-like stimuli are morphologically decomposed (even, in this case, for only partially productive morpheme stems, e.g., *inceive*). Dominguez, de Vega, and Barber (2004) compared morphological priming between pairs of Spanish words with a shared stem (*hijo/hija* [*son/daughter*]) to words that were not morphologically or semantically related, but shared a superficially similar stem (*foco/foca* [*floodlight/seal*]), and to those that were merely orthographically similar (*rasa/rana* [*flat/frog*]). They found that the brain rapidly distinguished between the morphologically- and superficially-related pairs; both elicited an initial amplitude reduction in the N400 time window, but this effect was sustained only for the morphologically (and thus semantically) similar pairs.

For many subsystems of inflectional morphology, regular patterns (e.g., in English past tense: *stretch/stretched*; in English plurals: *friend/friends*) can be contrasted with irregular ones (e.g., *catch/caught*; *woman/women*). Because electrophysiological measures reflect subtle processing differences between different classes of stimuli, they are well suited for determining the extent to which regular and irregular word forms are differentially processed. In three experiments, Penke et al. (1997) found that irregular past participle stems with the regular (i.e., incorrect) suffix *-t* elicited a left anterior negativity, whereas regular past participle stems with the irregular suffix *-en* did not. Weyerts et al. (1995) observed a similar-sized positivity from ~250 ms for both identity and morphological (infinitive) priming of past participles of regular verbs but a smaller and delayed morphological repetition effect relative to identity repetition for irregular verbs. In short, various ERP analyses do point to processing differences between regular and irregular morphological forms in adults, although it remains an open question exactly how distinct the neural representations of the two are.

4.2.2. Semantic relations between words

Reaction time and psychophysiological measures indicate that the processing of a single word (*cat*) is facilitated by the prior occurrence of a semantically related word (*dog*). This facilitation, known as semantic priming, is taken to reflect the way in which word representations are organized in our mental lexicon. Electrophysiological signs of semantic relations between words have been investigated primarily using the lexical decision task (Bentin, McCarthy, & Wood, 1985) and the category membership verification task (Boddy & Weinberg, 1981). In both tasks, ERPs to semantically primed words are more positive between 200 and 500 ms than are those to unprimed words, with the difference presumed to be a member of the N400 family. While the N400 effects in different modalities as well as cross-modally (Holcomb & Anderson, 1993) are similar in comprising a monophasic negative wave between 200 and 600 ms, they differ in amplitude, onset latency, and/or scalp distribution (Holcomb & Neville, 1990). Distributional differences notwithstanding, the reliability with which N400 amplitude is modulated by semantic relations has made it a useful metric for testing various hypotheses about language processing.

Among the more controversial issues in the semantic priming literature has been the relative contribution of "automatic" and "attentional" processes to the observed response facilitation (Den Heyer, Briand, & Dannenbring, 1983). This controversy grows out of the larger debate over the modularity of language abilities, with the assumption that modular processes are automatic. To determine whether the N400 indexes automatic lexical (modular) processes, or non-modular, controlled effects, researchers have examined the modulation of the N400 priming effect by factors such as the proportion of related and unrelated words (Holcomb, 1988; Chwilla, Brown, & Hagoort, 1995), the temporal interval between prime and target (Anderson & Holcomb, 1995), and subjects' attentional focus (McCarthy & Nobre, 1993). Overall, it seems that the N400 priming effect persists under conditions typically more associated with automatic processing, though it is often altered quantitatively.

Studies addressing the issue of automaticity via forward and/or backward masking likewise have found N400 priming effects either unchanged or present, albeit smaller (Brown & Hagoort, 1993; Deacon et al., 2000; Kiefer & Spitzer, 2000). Masked and unmasked words also appear to similarly *interfere* with N400 priming (Deacon et al., 2004), although some have reported the eradication of N400 effects with masking (Ruz et al., 2003). Whereas N400 priming effects generally persist under masking and in the attentional blink paradigm, in which streams of rapid input must be attended and processed for response, causing some stimuli to be behaviorally missed ("blinked"; Vogel, Luck & Shapiro, 1998), LPC priming effects (linked to explicit, as opposed to implicit, memory; Olichney et al., 2000) do not (Misra & Holcomb, 2003; Rolke et al., 2001). Taken together, the results suggest that the N400 indexes processing that is neither completely automatic, because it changes in size and timecourse with reduced attention, nor completely controlled, because it persists at least partially when conscious attentional resources are severely limited, as in stage 2 and REM sleep (Bastuji, Perrin, & Garcia-Larrea, 2002).

4.2.3. Other semantic relations

N400 responses are not limited to words. A negativity between 300 and 500 ms with a wide-spread, generally centrally-maximal distribution, which is reduced in amplitude in the presence of supportive context information, makes up part of the brain's response to *any* potentially meaningful stimulus, including line drawings and pictures (Ganis, Kutas, & Sereno, 1996), faces (Bobes, Valdes-Sosa, & Olivares, 1994), meaningful environmental sounds (Van Petten & Rheinfelder, 1995; Chao, Nielson-Bohlman, & Knight, 1995), and gestures (Kelly, Kravitz, & Hopkins, 2004). These types of stimuli, as well as odors (Castle, Van Toller, & Milligan, 2000), also serve as effective context for the N400 response to words, causing amplitude reductions when they are predictive. However, linguistic content does not seem to be necessary for eliciting an N400, which has been observed for anomalies within scenes (Ganis & Kutas, 2003), picture stories (West & Holcomb, 2002), and short video clips (Sitnikova, Kuperberg, & Holcomb, 2003).

The N400 seems to reflect access to stored information at a number of levels: certain aspects of orthography, phonology, and morphology, as well as physical featural similarity between referents of words (e.g., shared shape or size characteristics of named objects; Kellenbach, Wijers, & Mulder, 2000), and a variety of types of meaning relationships (e.g., categorical, associative, schematic), including spatial reference frames (Taylor et al., 2001). This, coupled with the fact that the N400 is sensitive to factors related to the ease with which information can be accessed from memory, has led to the suggestion that it indexes search through long-term, semantic memory. Indeed, N400-like potentials have also been observed in other domains in which memory search would seem to play a role, such as the processing of mathematical relationships among numbers (Galfano et al., 2004; Jost et al., 2003), though not all types of well-learned information elicit or influence N400s. For example, N400s are not observed to grammatical violations if these do not impact meaning, violations of melody (Besson & Macar, 1987) or prosody (Astesano, Besson, & Alter, 2004), or social expectancy (Bartholow et al., 2001) or to mismatches between faces and (recently learned) names (Huddy et al., 2003).

The N400 thus seems to index processing important for, but not limited to, language, which involves the access of relatively well-established, complex, and multidimensional representations from stimuli known from experience to be potentially meaningful. Potentials at the same latency, and sensitive to the same kind of semantic variables, are observed in the fusiform gyrus of patients with implanted electrodes (e.g., Nobre & McCarthy, 1995), although the inferotemporal cortex and superior temporal sulcus (which perform higher-order, modality-specific perceptual processing), as well as the medial temporal lobe, hippocampus, and ventrolateral prefrontal cortex (which process input from multiple modalities) are also active within this time window (Halgren et al., 1994a,b). The scalp-recorded N400 thus may reflect a set of temporally-restricted neural processes that are common to the analysis of all sensory inputs, allowing cross-modal interaction for the purposes of meaning construction (for MEG-based analysis, see Halgren et al., 2002).

4.3. Sentence comprehension

While the psychology of words is a rich field, analyses at the word level alone will not suffice to explain how meaning is derived from language, as even many aspects of words are difficult to understand without appealing to the sentence level or beyond.

4.3.1. Semantic context in sentences

The processing of words in sentences and how they are influenced by semantic and syntactic constraints have been extensively studied with ERPs. Kutas and Hillyard (1980) observed a large negativity peaking around 400 ms (N400) to a lexically semantically anomalous word at the end of a sentence; this has been replicated for written, spoken, and signed languages (see Figure 24.1). N400 elicitation, however, is not specific to semantic anomalies, and its amplitude reflects finer gradations of the contextual constraints placed on the eliciting word (Kutas & Federmeier, 2001). In fact, N400 amplitude and the cloze probability of a word (e.g., what proportion of subjects will fill in a particular word as being the most likely completion of a sentence fragment; Taylor, 1953) are inversely correlated at a level

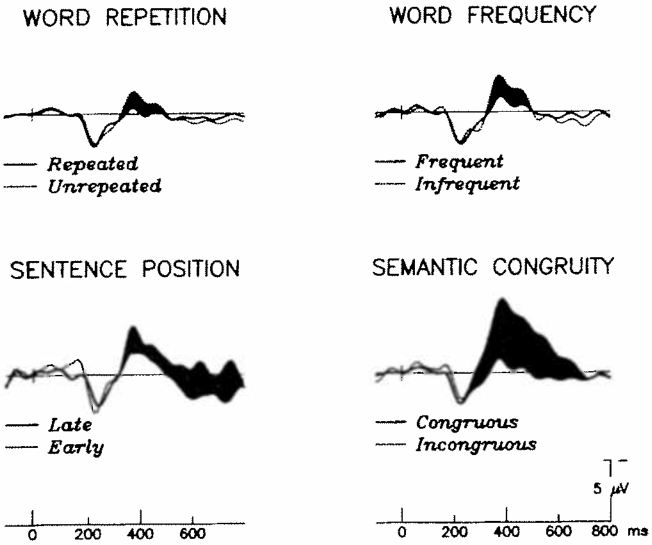

Figure 24.1. Sample N400 effects at a midline parietal site.

above 90%. Moreover, the finding that N400 amplitude to a low cloze word is the same regardless of the degree of prior contextual constraint was critical in establishing that the N400 does not index the violation of previously established expectancies for a particular word that was not presented, but rather the degree to which the sentence fragment prepares the way for the word that actually followed (Kutas & Hillyard, 1984). This effect of contextual constraint is also seen in the monotonic decrease in N400 amplitude to open class words with their ordinal position in congruent sentences, but not in random word strings of equal length. The semantic aspect of sentential context is also capable of eliminating the N400 frequency effect (Van Petten, 1995).

Contrasts of lexical/associative semantic relationships and sentence-level semantic relationships indicate that both independently influence N400 amplitude (Van Petten, 1995; see also Swaab et al., 2003, for a similar conclusion) and interact with comprehension skill (Van Petten et al., 1997). The N400 is sensitive to the relationships between a word and other words in the lexicon, its immediate sentential context, and discourse-level information, in both the auditory and visual modalities, as well as in nonverbal stories (West & Holcomb, 2002). van Berkum and colleagues (1999, 2003), for example, found that equivalent-sized N400s to the final words of isolated sentences like "Jane told her brother that he was exceptionally *quick/slow*" differed in amplitude when embedded in a discourse context like "That morning, Jane's brother finished his shower in only 5 minutes." It is important to note, however, that despite the exquisite sensitivity of the N400 to semantic relationships even outside of a sentence context and contextual expectancy (operationalized by cloze probability), it is not a good index of either sentential plausibility or meaning in terms of truth value: N400s to *white* are only marginally smaller than those to *sour* when completing sentence fragments such as "Dutch trains are —" (when they in fact yellow), are hardly present to *eat* in "For breakfast the eggs would only *eat*...", and are equally small to *bird* in "A robin is/is not a *bird*" (Fischler et al., 1983; Kuperberg et al., 2003; Hagoort et al., 2004).

The N400 also has been used to examine when and how context exerts its influence on word processing. Van Petten and colleagues (1999) found that auditory ERPs to congruent and incongruent sentence completions differ within 200 ms after word onset, before the auditory signal was sufficient to uniquely identify the words (according to a gating study). Furthermore, the N400 to incongruent words (*captive*) that shared initial phonemes with the expected completions (*captain*) deviated from that to the expected item significantly later than did the N400 to incongruent words that did not share initial phonemes. Inconsistent with a bottom-up integration account, listeners do begin semantic analysis with incomplete acoustic information from contextually-derived expectations (semantic and perhaps phonological), prior to word identification and semantic access.

Such results suggest that language comprehenders may use context not only to guide the integration of the bottom-up information gleaned from a word in that context, but to actively prepare for the processing of likely upcoming – but not yet presented – words. Indeed, a number of recent studies have provided evidence that normal language comprehension involves semantic (and perhaps lexical) prediction. For example, Federmeier and Kutas (1999a) asked participants to read pairs of sentences leading to an expectation for a particular item in a particular semantic category; e.g.:

Ann wanted to treat her foreign guests to an all-American dessert. So she went out in the back yard and picked some apples.

which terminated with the expected item (*apples*), an unexpected item from the expected category (*oranges*), or an unexpected item from a different semantic category (*carrots*). Though both unexpected endings – of equal cloze probability and plausibility – elicited a large N400 relative to the expected one, those from the expected category elicited smaller N400s, even more so in high than low constraining contexts. As this pattern goes in the opposite direction from the rated plausibility of these items, N400 amplitudes to the within category items seem to be largely a function, not of the plausibility of the word itself, but of the expected (but not presented) exemplars. This constitutes clear evidence for prediction given that the featural overlap between the within category violation (*oranges*) and the contextually expected item (*apples*) could affect processing only if the features of the expected item were already activated in the comprehender's mind.

Further evidence for prediction in sentence processing has come from a series of studies in which readers' or listeners' ERPs to articles or adjectives differ according to whether they matched or mismatched the gender of an *upcoming* noun (written, spoken or in picture form) – a difference that indicates contextually-based expectation for a noun of a particular gender, or prescience

(Wicha, Moreno, & Kutas, 2004; van Berkum et al., 2005).

Alongside this evidence for predictive processing mechanisms in whole brain language comprehension is a growing realization that the brain may employ *multiple* processing strategies. Federmeier and Kutas (1999b) examined hemispheric differences in sentence comprehension by lateralizing the sentence-final words of three category types as described above. Since stimuli presented in one half of visual space are processed preferentially by the contralateral hemisphere, this procedure reveals hemispheric processing biases. Federmeier and Kutas replicated the pattern observed for normal reading when target words were preferentially processed by the left hemisphere (right visual field), but observed only a difference between expected and unexpected endings (of both types, consistent with plausibility ratings) for left visual field/right hemisphere processing. Thus, whereas left hemisphere comprehension strategies involve prediction, right hemisphere processing appears more bottom-up, focused on the *integration* of the current word with context information.

4.3.2. Syntactic investigations

Two of the most important and hotly contested debates within linguistics and psycholinguistics, namely, (1) the competence versus performance distinction (section 4.3.2.1) and (2) the modularity of language representation and language processing (section 4.3.2.2) have played out most energetically with regard to the syntactic (phrasal and sentential) levels of linguistic analysis, as detailed below.

4.3.2.1. *The role of working memory, a performance construct, in syntactic processing.* The main focus of psychophysiological investigations of working memory (WM) in syntactic processing has been structures in which one sentence element must be associated with another at a distance (often across a clause boundary) in order for both to be interpreted correctly. In English, this is true of so-called "*wh*-questions", formed from "*wh*-words" like *who*, *what*, *which*, *where*, etc., and relative clauses. Any sentence constituent – subject, object, object of a preposition, even an entire prepositional phrase – can be displaced as a question word or relative pronoun from the position it would occupy in a corresponding declarative sentence (indicated in the examples by underlining) to the left periphery of a clause, as shown here for subjects and direct objects:

Declarative sentence:	She said [the reporter criticized the senator].
Subject *wh*-question:	***Who*** [did she say [__criticized the senator]]?
Subject relative clause:	The reporter [***who*** [she said [__ criticized the senator]]] . . .
Object *wh*-question:	***Who*** [did she say [the reporter criticized __]]?
Object relative clause:	The senator [***who*** [she said [the reporter criticized __]]] . . .

The displaced element is referred to as a "filler," and the corresponding underlined position is referred to as a "gap" (Fodor, 1978), reflecting the fact that the gapped position must be "filled" with some such displaced constituent for sentence interpretation to succeed, and that the two are interdependent: fillers without gaps are illicit (*Who did she say the reporter criticized the senator?), and gaps without licensing fillers are equally ill-formed (*Did she say__ criticized the senator?). For this reason, structures of this nature are generally referred to as dependencies. Just exactly how the association of gaps with their fillers is effected in linguistic representation and processing is a long-standing unresolved issue.

Gaze duration (Holmes & O'Regan, 1981), word-by-word reading times (King and Just, 1991), and pupillary diameter measures (Just & Carpenter, 1993) have established that, in English, object relative clauses are more difficult to process than are subject relative clauses, due in part to the added load they place on working memory. Information provided earlier in the sentence (the filler) must be maintained over time in order to determine the correct identity of the corresponding gap, and in object dependencies this information must be maintained over a longer distance while the processing of additional material continues (Kluender, 1998; Gibson, 2000).

In an ERP study of English *wh*-questions, Kluender and Kutas (1993a,b) showed in word-by-word comparisons of sentence positions between filler and gap that, relative to control sentences, object questions reliably elicited greater negativity over left anterior regions of scalp between 300 and 500 ms post-word onset (left anterior negativity, or LAN), while subject questions did not, presumably due to the increased working memory load of object dependencies. Direct comparisons of subject versus object relative clauses in the visual (King & Kutas, 1995) and auditory (Müller, King, & Kutas, 1997) modalities in English over longer time windows revealed that these phasic effects were most likely time slices of slow anterior negative potentials (left-lateralized with visual but not auditory presentation; see Figure 24.2). In a related paradigm comparing biclausal structures that differed only in the first word ("After/Before the scientist submitted the paper, the journal changed its policy"), Münte, Schiltz, and Kutas (1998) showed that "before" sentences with reversed chronological order similarly elicited slow negative potentials over left anterior sites, which were directly modulated by working memory capacity. Studies of *wh*-questions in German (Kluender & Münte, 1998; Fiebach, Schlesewsky, & Friederici, 2001; Felser, Clahsen, & Münte, 2003) and objects displaced leftwards ("scrambled" in linguistic terminology) in Japanese (Ueno & Kluender, 2003) essentially replicated the English results.

Other studies have added to this overall picture. Because of the idiosyncrasies of German word order, the use of German nouns ambiguously marked for nominative (subject) versus accusative (object) case can postpone the disambiguation of subject from object relative clauses and questions until the final word of the clause. When this is the

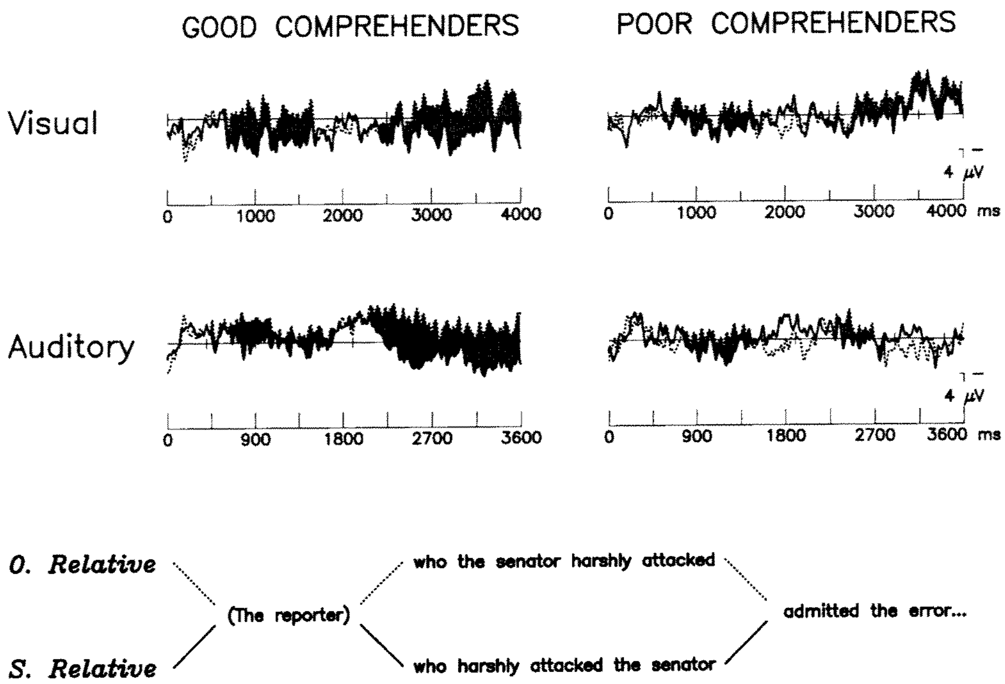

Figure 24.2. Comparison of grand average ERPs to subject relative (solid line) and object relative (dotted line) sentences from a left anterior site in good and poor comprehenders for word by word (500 ms/word) reading and natural speech. The visual data are taken from King and Kutas (1995) and the auditory data are taken from Mueller, King and Kutas (1997). Reprinted by permission of the authors.

case, readers appear to prefer and expect subject dependencies, as evidenced by the fact that the final word of object dependencies elicits a late positivity similar to that seen in response to dispreferred parses and ungrammatical stimuli – the P600 (Mecklinger et al., 1995) – though primarily in participants with high verbal working memory spans (Bornkessel et al., 2004).

Kaan et al. (2000) found that the association of a filler with its gap in English object questions similarly elicits a late positivity, which they interpreted as associated with integration rather than with storage costs of syntactic working memory (Gibson, 2000). This effect of gap-filling also has been replicated in verb-final languages like German (Fiebach, Schlesewsky, & Friederici, 2001; Felser, Clahsen, & Münte, 2003) and Japanese (Ueno & Kluender, 2003).

Overall, these studies conform to the generally accepted linguistic analysis of long-distance dependencies and point to its psychological reality with regard to the processing mechanisms involved. A related line of inquiry in the neural imaging literature has focused on the localization of such mechanisms by studying differences in activation of cortical areas in response to subject versus object dependencies. In an fMRI study, Just, Carpenter, and Keller, (1996) compared subject and object relative clauses with control sentences containing conjoined clauses, and found left-lateralized activation in both Broca's and Wernicke's areas in response to both relative clause conditions, with object relative clauses showing the greatest levels of activation. They interpreted these findings as reflecting general working memory demands distributed across multiple cortical areas, directly or indirectly subserving lexical and syntactic processes (Keller, Carpenter, & Just 2001).

A series of PET studies by Caplan and colleagues comparing subject and object dependencies produced differing but mostly consistent results (Stromswold et al., 1996; Caplan, Alpert, & Waters, 1998, 1999; Caplan et al., 2000). Overall, this series of studies consistently elicited activation in the inferior frontal gyrus (BA 44 or 45) – and less consistently in the anterior cingulate, medial frontal gyri, and the superior parietal lobe – in response to object dependencies. These were interpreted as a measure of syntactic complexity related to syntactic integration processes. Subsequent studies, however, failed to confirm this precise picture. Caplan et al. (2001), for example, in an attempted replication of Just, Carpenter, and Keller, (1996), found that object versus subject relative clauses yielded activation of the left angular gyrus (BA 39), and marginal activation in the adjacent portion of the left superior temporal gyrus (BA 22) – essentially Wernicke's area. Ben-Shachar and colleagues (2003; 2004) reported greater activation of left inferior frontal cortex, but also of the posterior superior temporal gyrus bilaterally, when various types of object dependencies in Hebrew were compared with conditions lacking long-distance dependencies; no such effects were seen in direct comparisons with subject dependencies.

Cooke et al. (2001) manipulated the linear distance between filler and gap as well as clause type, and found that all long (relative to short) filler-gap conditions consistently elicited activation in the right posterior superior temporal gyrus. Holding filler-gap length constant, comparisons of object relative clauses with subject relative clauses produced activations in the left posterior temporal-occipital area and the right lingual and fusiform gyri, but not in inferior frontal regions. Only when object relative clauses with long filler-gap distances were compared to either subject or object relative clauses with short filler-gap distances was there activation in left inferior frontal cortex, albeit BA 47. In a similar study of German *wh*-questions, Fiebach, Schlesewsky, and Friederici (2001) likewise failed to find activation in left inferior frontal regions except when object questions with long filler-gap distances were compared to subject questions with short filler-gap distances; they linked Broca's area to syntactic working memory resources, rather than to syntactic integration costs related to syntactic complexity.

Caplan, Waters, and Alpert (2003) and Waters et al. (2003) used the Stromswold et al. (1996) stimuli to examine individual differences in the processing of relative clauses. Both studies reported correlations with processing speed rather than working memory capacity; inferior frontal areas (left-lateralized in the first study, bilaterally in the second) were activated in response to object relatives only in subjects with fast reaction times, while slow-responding subjects showed activation only in left parietal (first study) or superior temporal areas (second study).

In short, there seems to be some relation between the processing of object dependencies, particularly those with long distances between filler and gap, and the activation of left inferior frontal regions. Though consistent with the left lateralization of slow anterior negative potentials to object dependencies in ERP studies, this is unlikely a direct one-to-one mapping, but rather part of a more complex neural network, as suggested by the additional, disparate areas activated by object dependencies in most neural imaging studies (cf. Keller, Carpenter, & Just 2001).

The status of working memory processes in the processing of object dependencies remains similarly unclear at this point. While all the ERP studies cited are consistent with the hypothesis that left anterior negativity (LAN) is an index of working memory resources engaged in the processing of more difficult object dependencies, the exact correlation has not yet been conclusively established. King and Kutas (1995) showed that better relative clause comprehenders had larger LAN responses, but this can at best be taken as an indirect measure of working memory capacity. Münte, Schiltz, and Kutas (1998) showed a direct correlation between working memory capacity as measured by reading span and LAN amplitude, but not in a study of long-distance dependencies. Finally, the direct correlation in the Fiebach, Schlesewsky, and Friederici (2001) study of German *wh*-questions was not in the expected direction.

Discrepancies between ERP studies and neural imaging studies further complicate the picture. The Cooke et al. (2001) and Fiebach, Schlesewsky, and Friederici (2001, 2002) studies both suggest that activation of left inferior frontal areas of cortex is tied to the processing of long-distance object dependencies that especially tax working memory, not object dependencies *per se*. If so, then the role of working memory in long-distance dependencies may indeed be more of a performance than competence factor. On the other hand, the corresponding Fiebach, Schlesewsky, and Friederici (2001) ERP study reported a shorter but reliable anterior negativity in object versus subject questions with short filler-gap distances, perhaps indicating a greater sensitivity of ERP measures to such transient responses. Finally, the finding of Waters et al. (2003) that working memory capacity does not differentiate localization of cortical response to object dependencies (i.e., both high- and low-capacity subjects show bilateral activation in the inferior frontal lobe), while speed of sentence processing does (i.e., only high-proficiency subjects show bilateral inferior frontal activation) points to the fact that other individual differences contributing to overall proficiency need to be taken more seriously in future investigations as well. The bilingual neural imaging literature serves as a useful reference point in this regard, as it has convincingly shown that proficiency level is also a better predictor of second-language cortical representation than age of acquisition (Perani et al., 1998). Given what we now know about the plasticity of cortical representation (Merzenich et al., 2001), this should come as no surprise.

4.3.2.2. *The role of modularity in syntactic processing.* Within sentence processing, there are two separate but related areas of investigation with regard to modularity. One has to do with the dissociation of syntactic from semantic aspects of processing (section 4.3.2.2.2); the other has to do with the dissociation of automatic from controlled aspects of syntactic processing itself (section 4.3.2.2.1). In both cases, the intended contrast is between the automatic processes inherent in a phrase structural parsing module, and more controlled processes like semantic interpretation, which are considered to be the purview of a central processor. Since specialized modules by hypothesis feed into the central processor, which takes their output as its own input, controlled processes within the central executive are presumed to occur later within the overall processing stream than automatic, modularized processes, and to be associated with a different underlying neural system.

The fine-grained temporal resolution of ERPs together with the possibility of, at least inferentially, dissociating the neural processes associated with different types of cognitive events by examining their various parameters (polarity, latency, overall morphology, and scalp distribution) have fueled a large body of research aimed at teasing apart automatic from controlled processes, at the same time that PET and fMRI have been used to look for localization differences, as reviewed below.

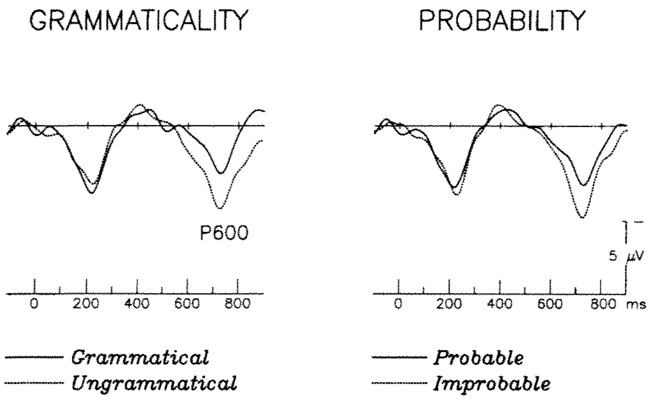

Figure 24.3. Grand average ERPs to mid-sentence words at a right parietal site: ungrammatical versus grammatical continuations (left), and improbable (20%) versus probable continuations, regardless of grammaticality (right). Data from Coulson, King, and Kutas (1997).

First, it may be useful to briefly give an overview of the three main ERP components that figure in these debates: the N400, the LAN, and the P600. The N400 component is discussed at length in sections 4.1.2, 4.2.2, and 4.3.1. Kutas and Hillyard (1983) attempted a dissociation of the N400 to violations of semantic well-formedness from potentially different ERP responses to violations of grammatical (morphosyntactic) well-formedness, including violations of number agreement between subjects and verbs ("she dig") and within noun phrases ("a balloons"), as well as the use of finite and non-finite verb forms in inappropriate sentence contexts ("to stayed", "are consider"). Significant early negative differences (300–400 ms) were found in all three conditions over anterior sites, together with marginally significant late positive differences over parietal sites 300 ms post-onset of words immediately following grammatical violations (Kutas and Hillyard, 1983: p. 544, Figure 4). Kutas and Hillyard thus noted that the association of the N400 with semantic but not grammatical anomalies pointed to non-identical processing systems.

It was not until a decade later, however, that the significance of these other components became apparent when a spate of exploratory ERP studies of syntactic processing (Neville et al., 1991; Osterhout & Holcomb, 1992; Hagoort, Brown, & Groothusen, 1993; Kluender & Kutas, 1993a) confirmed the existence of both a left-lateralized anterior negativity (LAN) between 300 and 500 ms post-stimulus onset, and a later broad positive shift (500–800 ms) with a more central distribution (P600; see Figure 24.3). These ERP components were elicited in response to various manipulations of sentence structure, and contrasted with the N400s to semantic manipulations within the same experimental designs. While the polarity and latency of the LAN (or family of such negative potentials) are essentially the same as that of the N400, they differ in their eliciting conditions, scalp distribution and morphology. Both the distribution and the latency of the P600 vary more widely: while it typically exhibits a posterior distribution, it sometimes appears over anterior regions of scalp (Osterhout & Holcomb, 1992), and it can onset as early as 200 ms (i.e., overlapping the P200 component).

After these early studies, much effort went into characterizing exactly which cognitive processes each potential might be indexing. With regard to the P600, the main debate centers on whether or not it is specific to syntactic processing (Osterhout & Hagoort, 1999), or reflects instead the engagement of a more general purpose process, reflected by a family of positive potentials known as the P3, especially the P3b (cf. Donchin & Coles, 1988), to unexpected but task-relevant anomalies of various types (Gunter, Stowe, & Mulder, 1997; Coulson et al., 1998a,b). In line with the latter view, a number of studies have demonstrated similar late positivities in response to various violations of semantics or pragmatics – either following the N400 response (Münte et al., 1998) or replacing it altogether (Shao, 1995; Kolk, Chwilla, van Herten, & Oor, 2003; Stowe, Kuperberg, Sitniknova, Caplan, & Holcomb, 2003; Hoeks, Stowe, and Doedens, 2004; van Herten, Kolk, & Chwilla, 2005) – and in response to orthographic violations that leave correct pronunciation intact (Münte et al.1998), harmonic violations in music (Patel et al., 1998), and violations of arithmetic rules (Nunez-Pena & Honrubia-Serrano, 2004). In line with the former view, it has been reported that the P600 elicited by syntactic anomalies is absent in patients with lesions of the basal ganglia (Frisch et al., 2003; Kotz et al., 2003; however, not in Friederici, von Cramon, & Kotz, 1999) and reduced in patients with Parkinson's disease (Friederici et al., 2003), though patients with basal ganglia lesions produce normal P300 responses in an auditory oddball paradigm. There is a related debate regarding the functional significance of the P600 within language contexts: should it be considered an index of syntactic processes *per se* (Hagoort, Brown, & Groothusen 1993), of late, controlled processes of reanalysis and repair once a syntactic parsing error has been detected in a multi-stage parsing model (Friederici, Hahne, & Mecklinger, 1996), of syntactic integration processes in general (Kaan et al., 2000), of the reanalysis necessitated by any kind of linguistic parsing difficulty (semantic, morphosyntactic, or orthographic; Münte et al., 1998), or of structural integration processes generally construed (Patel et al. 1998)?

With regard to the LAN, the first challenge was to tease apart the influence of (morpho)syntactic violations versus that of working memory in syntactic processing. Early studies reported LANs both to violations of syntactic well-formedness (Neville et al., 1991; Friederici, Pfeifer, & Hahne, 1993) as well as to manipulations of syntactic working memory (Kluender & Kutas, 1993a,b; King & Kutas, 1995). Kluender and Münte (1998) showed anterior negativities to manipulations of both working memory load and grammaticality within the same experimental design: the negativity elicited by WM manipulations consisted of slow frontal potentials (as in King &

Kutas, 1995), which could also be seen in individual word responses, while the negativity to syntactic violations consisted of more reliably left-lateralized phasic responses. At times, these phasic responses can be bilaterally distributed as well, under auditory (Hahne & Friederici, 2002) and visual (Hagoort, Wassenaar, & Brown, 2003) stimulus presentation.

Much discussion has also focused on the existence of a left anterior negativity that starts 150–200 ms earlier than the LAN, but usually persists into the same 300–500 ms latency window, and exhibits the same scalp distribution. This early left anterior negativity or ELAN (Neville et al., 1991; Friederici, Pfeifer, & Hahne 1993) is sometimes but not always elicited by word category violations, which occur when the parser's expectation that the next incoming word will be of a particular grammatical category (e.g., a noun following an article and adjective, such as "the red . . . ") is violated. What remains unclear is whether the ELAN, which has been elicited only in manipulations of this kind, is a response to the presence of the unexpected word category (a verb following "the red...") or the absence of the expected category (e.g., a noun).

4.3.2.2.1. *The relationship of automatic and controlled syntactic processes.* Frazier and Fodor (1978), among others, proposed that parsing consists of at least two stages, an initial structure-building process based on hierarchical phrase structure and independent of meaning, and a later phase of syntactic reanalysis that comes into play when the initial parse fails and requires revision. Part of the motivation for such a model came from so-called "garden path" sentences (e.g., "The horse raced past the barn fell"), in which the parser is essentially led "down the [wrong] garden path." In this classic example, the parser initially attempts to analyze this sentence as containing an intransitive verb, but is stymied by the sentence-final verb "fell," which forces a reanalysis of "raced" as a passive participle within a reduced relative clause ("The horse [that was raced {by some unspecified rider} past the barn] fell"). The claim has been that the first (-pass parsing) process is automatic, not under conscious control, and impervious to non-syntactic influences, whereas the second process of revision or reanalysis is instead a conscious, controlled process that interacts with other types of information, such as that provided by semantic and/or pragmatic context.

An obvious factor contributing to the garden path phenomenon during silent reading is the lack of prosodic information or intonational contours that are superimposed on the words "raced" and "barn" to mark the (prosodic) boundaries of the reduced relative clause. Such prosodic boundaries help to avoid the garden path effect, and are reflected in the brain's responses to spoken sentences as a positive deflection in the ERP, known as the closure positive shift (Steinhauer et al., 1999); they are also elicited to a lesser degree for subvocal prosodic phrasing in written texts that include punctuation such as commas (Steinhauer, 2003).

Since the earliest studies of syntactic parsing reported both LAN and P600s to grammatically ill-formed stimuli, and since the two components have essentially complementary latency windows (300–500 ms and 500–800 ms, respectively), there has been an understandable attempt to map these components onto different stages of syntactic parsing (Friederici, Pfeifer, & Hahne, 1993; Osterhout et al., 1994). Most researchers now agree that the P600 most likely reflects either revision or integration – under either interpretation, a controlled process – despite the lack of consensus on whether the P600 is specific to syntactic processing, much less to language (see 4.3.2.2).

The existence of ERP markers of earlier, automatic stages of syntactic processing is similarly controversial. In particular, the exact relationship of the ELAN (100–300 ms), and the LAN (300–500 ms), has not been conclusively established, as in most paradigms that elicit an ELAN there is also a LAN present. In any case, the LAN is taken to precede semantic processes indexed by the N400, and dissociations of the two by factors that suppress the N400 but not the LAN have been demonstrated in normal populations (Friederici et al., 2004; Friederici, Steinhauer, & Frisch, 1999; Hahne & Friederici, 2002; Hahne & Jescheniak, 2001). Dissociations of the (E)LAN from the P600 have similarly been demonstrated in normal populations (Hahne & Friederici, 1999) and in patients with left frontal cortical lesions (Friederici, von Cramon, & Kotz, 1999).

While the imperviousness of the ELAN to experimental manipulations of this type and its suppression under degraded visual presentation suggest that it may index automatic processes, the component has to date been reliably elicited using only one general stimulus paradigm. The validity of claims made from the ELAN thus must await further research.

4.3.2.2.2. *The relationship of syntactic and semantic processes.* Although there is general agreement that comprehension requires reconciliation of semantic information about what the words in a sentence might mean and structural information about how they relate to each other, a heated debate rages as to whether or not initial syntactic analyses are modular (informationally encapsulated) and, at least initially, operate automatically, isolated from more controlled semantic/conceptual/pragmatic processes. There are fMRI data consistent with both theoretical perspectives. On the one hand, some brain areas appear to be selectively activated during semantic (e.g., BA 47 in the anterior LIFG) or syntactic processing (BA 44 in the posterior LIFG for word order processing, (Dapretto & Bookheimer, 1999; Indefrey et al., 2001), consistent with the possibility that these two levels of analysis can proceed independently. On the other hand, neuroimaging investigations offer no shortage of substrates for semantic-syntax interactions – many brain areas that are reliably activated during both semantic and syntactic tasks (Kaan & Swaab, 2002), with activation patterns that differ only in degree (Kang et al., 1998; Kuperberg et al., 2003; Ni et al., 2000), Moreover, to the extent that researchers have explicitly sought semantic-syntax interactions, such patterns have been found in Broca's area (Röder et al., 2002), the frontal operculum in the LIFG, and the left anterior STG (Friederici, Meyer, & von Cramon, 2000).

ERP data are equally equivocal on this issue. When researchers have combined semantic violations and syntactic violations and compared the brain's response to such double violations with that for each of the simple violations alone, they have consistently found that the LAN – viewed by some as an early sign of syntactic parsing operations – is insensitive to semantic manipulations (Gunter, Friederici, & Schriefers, 2000; Gunter, Stowe, & Mulder, 1997). Based on such evidence, Friederici and her colleagues argue that the earliest parsing operations proceed impervious to semantic information (see section 4.3.2.2). The results for the processes reflected in the N400 and P600, however, are less straightforward.

Several laboratories have demonstrated that N400 effects triggered by semantic manipulations are modulated by a number of different morphosyntactic factors. For example, the N400 to a semantically anomalous (versus congruent) noun in a sentence is larger when the semantic violation co-occurs with a mismatch between either the gender or the number of the noun and that of an associated article (Hagoort, Wassenaar, & Brown, 2003; Wicha, Moreno, & Kutas, 2004). Though this apparent "syntactic boost" in N400 amplitude could be a spurious consequence of overlap between an N400 and a LAN elicited by the syntactic violation (Gunter, Friederici, & Schriefers, 2000), its posterior scalp distribution favors the view that it is an increase in N400 amplitude per se. This could be an increase engendered by the additional load placed on semantic integration processes by the concomitant need to deal with the syntactic inconsistency (Hagoort, 2003). An increase in N400 amplitude triggered by verb inflection violations even in the absence of a semantic violation likewise attests to N400 sensitivity to morphosyntactic variables (Gunter & Friederici, 1999). These sorts of data thus seem to indicate an interaction of certain semantic and syntactic variables between 200 and 500 ms after word onset. However, word-category violations seem to suppress the significant N400 increase that would otherwise have been elicited by a semantically anomalous word (Friederici et al., 2004; Friederici, Steinhauer, & Frisch, 1999; Hahne & Friederici, 2002; Hahne & Jescheniak, 2001), in line with a more modular syntax-first view of sentence processing, with the breakdown in phrase-structure building due to a syntactic violation effectively shutting down any subsequent semantic analysis (Friederici et al., 2004).

Assessing semantic effects on the P600 component, typically linked to moments of syntactic ambiguity or outright violation (but see section 4.3.2.2), is complicated by the fact that it often follows close on the heels of an N400, as in double violations, leading to at least partial overlap of the two. Smaller positivity in the P600 time window to double violations might thus reflect less P600 activity per se or partial overlap with a larger preceding N400. In fact, the inference with regard to the independence versus interaction of semantic and syntactic processes hinges on how P600 amplitude is measured. Measured with respect to a pre-stimulus baseline, semantic fit and grammatical factors (gender agreement or verb inflection) seem to interact, with the P600 to double violations smaller than to pure grammatical violations (Wicha, Moreno, & Kutas, 2004), perhaps because less effort is devoted to syntactic re-analysis (smaller P600) when finding meaning is difficult (Gunter, Friederici, & Schriefers, 2000). In contrast, when P600 amplitudes are measured with reference to the immediately preceding N400 peak, the interaction between semantic and morphosyntactic factors does not reach statistical significance, perhaps reflecting independence (Hagoort, Wassenaar, & Brown, 2003; though see Wicha, Moreno, & Kutas, 2004).

Though N400s are especially sensitive to semantic manipulations, P600s fairly reliably modulated by parsing difficulties, and LANs often elicited by morphosyntactic violations, the jury is still out on whether these brain potentials reflect psychophysiological primitives that readily map onto individual linguistic processes or representations. Indeed, it may be a mistake to attempt functional brain surgery (or phrenology) according to predetermined linguistic categories. Since neither psychophysiological measures nor linguistic analyses are completely above reproach, it may ultimately prove more rewarding to investigate what functions brain circuits actually compute, and how these could yield the types of regularities that linguists and psycholinguists have uncovered over the years. It may also be useful to bear in mind that the language comprehender's main goal is not to identify or categorize linguistic errors, but to make sense – whenever possible – of the available linguistic input.

4.4. Language production

While language production has been less thoroughly investigated with neuroimaging (especially electrophysiological) techniques than language comprehension, this gap has been narrowed in the past six or so years with the development of the lateralized readiness potential (LRP) and the no go N200 effect. Both have been used to delineate the relative time course of information transmission (encoding and/or retrieval) within a two choice go/no go paradigm, typically involving tacit picture naming.

The LRP is derived from a negative-going readiness brain potential (RP) that develops around 800 or so ms prior to a voluntary movement (Kornhuber & Deecke, 1965); a few hundred ms before the actual movement, the RP becomes larger over the central scalp contralateral to the moving hand. Single cell recordings from monkey cortex indicate that the lateralized portion of the RP is generated, at least in part, in the primary motor cortex (Miller, Riehle, & Requin, 1992).

The LRP is a derived measure computed in the stimulus-locked average with respect to the correct hand (Coles, 1989). On each trial, potentials from left (C3′) and right hand (C4′) areas are subtracted from one another (equivalent to a bipolar C3′–C4′ recording), yielding the lateralized portion of the RP. These difference RPs are then averaged separately for trials where each hand was the correct response and subtracted from each other, canceling lateralized potentials unrelated to response preparation and leaving the average lateralization associated with response preparation – the LRP. Response preparation thus can be monitored a few hundred ms prior to an overt response and even when no response is given: its polarity indicates which response hand is being prepared and its amplitude indicates the degree of preparation, with overt response initiation triggered when LRP amplitude exceeds a certain threshold. The LRP is thus taken as a real-time measure of selective response preparation.

Also appearing in stimulus-locked averages within a dual choice go/no go task, when the motor response is withheld as per the cued instructions, is a fronto-central negativity (1–4 uV) with a latency that varies with task demands. This no go N200 is presumed to reflect response inhibition processes within the frontal cortex, based on single unit activity patterns in monkey frontal cortex during go/no go tasks, and suppression of the monkey's overt response on go trials by stimulation of prefrontal cortex at the time a no go N200 would have occurred if the response were withheld (Sasaki, Gemba, & Tsujimoto, 1989; see also Casey et al., 1998 for supporting fMRI evidence). The peak latency of the N200 effect (go minus no go ERPs) is typically taken as an upper estimate of the time by which the information needed for the go/no go decision must have been encoded. Overall, the N200 is larger, more robust, and more reliably elicited across individuals than is the LRP.

Essentially the same experimental paradigm (two choice go/no go paradigm) has been employed to delineate the relative time course of availability of different types of linguistic information (conceptual, semantic, word form or lemma, syntactic, phonological) during tacit picture naming. Participants view line drawings and are asked to make two decisions on the basis of the depicted item's characteristics (semantic versus phonological decisions as in van Turennout, Hagoort, & Brown, 1998; Schmitt, Münte, & Kutas, 2000; semantic versus syntactic decisions as in van Turennout, Hagoort, & Brown, 1998; Schmitt et al., 2001). Within an experimental setting, one decision maps onto the responding hand (which hand executes the response if there is one) and the other onto the go/no go choice (whether or not any overt response is given) and vice versa.

Though tacit naming in such a design is not actual language production, it is assumed that decisions (necessary for implicit as well as overt naming) made during a trial render the semantic, conceptual, syntactic and phonological properties of the depicted item available, with a time course measurable with psychophysiological measures and without the accompanying artifacts of overt speech. Moreover, it is assumed that (in may cases, even partial) information is transmitted to the response system as it becomes available. Accordingly, if the responding hand is mapped onto information that is available faster than the information that determines whether or not any response is given, then there will be some response preparation (LRP activity) on no go trials, at least until the information needed for the go/no go decision is available to halt response preparation. LRP presence on no go trials with this mapping but not the reverse thus reflects the temporal availability advantage of one information type over another. This temporal advantage is also presumably reflected in the onset and peak latencies of the N200 no go effect (no go minus go difference), as the N200 for no go trials can occur only after enough relevant information that the response is to be withheld has accrued.

Overall, the results of these electrophysiological studies of language production have been remarkably consistent. On average, following a pictured item, conceptual/semantic information is available by ~150 to 225 ms, syntactic (gender) information is available by ~225 to 275 ms, and phonological information is available by ~ 275 to 400 ms. These results then indicate that semantic processing precedes syntactic processing, which in turn precedes phonological processing. These results, however, cannot be used to distinguish between models of language production that argue for or against strict seriality wherein phonological processing is temporally contingent upon a full syntactic analysis and/or syntactic processing is contingent on a complete semantic analysis (Rahman, van Turennout, & Levelt, 2003).

5. CONCLUSIONS AND FUTURE DIRECTIONS

Psychophysiological data have thus converged with behavioral data to fashion a set of viable hypotheses about *when* and *where* language processes occupy the brain – data that in some cases also constrain accounts of *how* language processing (reading, listening, preparing to speak) must be transpiring in real time. The past few decades or so of research attest to the multifaceted nature of language. Indeed, language processing involves an astonishing array of computational and neurobiological processes that operate on a large number of representation types at a number of different time scales in much of the brain's expanse. Much research effort has gone into cataloging and understanding these differences, such that we now know something about the different information types that are typically activated, their relative order of availability, their relative importance, and their relative independence, as well as something about the brain areas involved. Even routine language processing seems to engage considerable amounts of the brain, including not only cortical but also subcortical regions, and, within the cortex, areas in every lobe and in both hemispheres, although typically not to the same extents.

Recent work has highlighted the right hemisphere's role in language comprehension, revealing that it performs functions that are arguably as critical for real understanding as those under the purview of the left hemisphere. More neuroimaging studies of nonliteral language processing in the coming years will be a welcome addition to the existing handful on metaphor, jokes, indirect speech acts, and the like, in our aim of understanding not only the right hemisphere's capacity for and involvement in language but also the nature of the differences, if any, between literal and nonliteral language processing. A relatively new approach to these issues combines neuroimaging techniques with the visual half field paradigm – an excellent way to get a sense of how each hemisphere in the intact brain reacts to input when it receives a slight processing headstart. However, ultimately, we need to face the challenge of explaining how the two hemispheres work in unison during language while making use of the different processes and representations that previous research has defined. Understanding language as an integrated, goal-directed process will moreover require elucidation of the relationships holding among language subcomponents, and between language and other cognitive abilities.

There is as of yet surprisingly little consensus on precisely which brain areas are essential for – as opposed to merely involved in – language processing, their exact computational function(s), and therefore on their specificity for language. Likewise, there is still remarkably little accord among researchers about the degree to which language representations and/or processes (if such a sharp distinction is ultimately viable) are functionally isolable from non-linguistic representations and/or processes, or, within the domain of language, whether or not any subprocesses are isolated from each other. Moreover, whatever one's stance with respect to these issues, we are all comparatively illiterate with respect to how, if at all, the answers to these questions are tempered by individual differences of any kind (age, personality, mood), the particular language or type of languages under investigation (different languages or modalities of linguistic input), and/or the specifics of the dependent measures and/or experimental paradigms with which the questions are probed.

Even experiments that go beyond the single word to include whole sentence processing, discourse, text, and nonliteral language are a far cry from the types of communicative interactions that we encounter daily outside the laboratory. And, indeed, a few researchers are breaking new ground in their inquiry into more natural language processing, so-called "language in the wild," which arrives in fits and starts with pauses, false starts, repetitions, and without a complete sentential structure. Neuroimaging researchers also have begun to explore the communicative role of gestures. Yet another direction of current research pays homage to the crucial social aspect of language acts by recording brain activity from two participants in parallel or from only one participant in the conversational presence of another. In addition, even within the sterile context of the laboratory, increasingly more neuroimaging researchers are beginning to appreciate that individual and group differences in age, working memory capacity, physical and intellectual experiences and general knowledge, psychological and emotional traits and states, as well as biological gender, all may impact the pattern of behavioral and neuroimaging results obtained, and thereby the inferences that we are likely to draw from them. One consequence of this is that researchers are sorting experimental participants into group types as a function of other criteria or subjecting the data to correlational analyses. Such an approach may help to explain the substantial variance in the neuroimaging data that seems to characterize even the best experimental designs.

Much of this variance comes from differences in what we know. And, what we know not only influences what we ultimately understand from language input but also the very processes by which we make sense of that input – determining what information is activated and in what order and with what strength, and how quickly an utterance or text is functionally stored for subsequent retrieval. Very little is known, however, about the relative importance of immediate context and longer-term background knowledge for meaning construction, and future research will need to address their interaction. It will also be important to understand just how critical it is for what is comprehended and/or how comprehension proceeds that people's experiences take place within human bodies with sensory receptors, motor effectors, and the brain betwixt. More research will be devoted to delineating how language representations are built out of both abstract, linguistic features and concrete, perceptual features.

There is also a continued need to explore connections between language processing and other cognitive feats, such as visual scene analysis, the understanding of diagrams, and the perception of music, as these activities likewise require that meaning be obtained over time from a well-structured source of information. By understanding the similarities (and differences) between these types of cognitive processes, we gain insight into the general principles underlying all of cognition, as well as an increased understanding of the defining properties of language.

In large part, psychophysiological data tend to be used either atheoretically, as findings to add to some database of what we know about when, or where any particular factor may have its influence on some brain (and/or behavioral) measure, or theoretically, as empirical evidence for (or in a few cases against) some particular point of view or hypothesis. Misguidedly, however, many instances of this latter use tend to be offered as empirical support for some position when they are just not inconsistent with it. In some cases, the authors seem to believe in their theory so strongly that almost any significant effect within the neuroimaging data constitutes support for the biological plausibility and validity of the original theory. Tempting as this may be, it is not a particularly productive approach to scientific inquiry. Nor is intentionally or unintentionally ignoring relevant data from another imaging modality. Indeed, one of the biggest challenges facing us in the next few decades will be how to make sense not only of discrepant results, but of the data from different imaging modalities, as we still know so little about the fundamental relationships among them. It should go without saying that the more we continue to learn about the physiological and physical basis of our measures and their sensitivities to external and internal energies, the better. However, even with what we know now, we can begin to use psychophysiological data not only to give body to our favorite linguistic theories, but to develop theories of brain functioning which can account for our brain's ability to understand and to produce language, the types of miscommunications and breakdowns that routinely do or could never occur, the nature and time course of language development and usage across the lifespan for a first language, a second language, or more, as well as language processing in individuals experiencing abnormal language experiences due to innate or experiential factors.

In the future, then, using the various and sundry psychophysiological tools at our disposal, we may yet come to understand how Dickinson used her brain to generate poems – which we use our brains to decipher and appreciate.

ACKNOWLEDGMENTS

This work was supported by funds from HD22614 and AG08313 to M. K. and was written while M. K. was a Lady Davis Fellow at Hebrew University of Jerusalem.

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