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Language in Microvolts

Marta Kutas
University of California, San Diego

Bernadette M. Schmitt
Maastricht University

Language mediates between thoughts and motor commands in a speaker, and between acoustic or visuospatial signals and thoughts in a listener. This mediation takes place in the brain. The brain is the machine that takes sounds, letter strings, or hand shapes as input and somehow yields the phenomenological sense of understanding. The brain is also the machine that controls the mouth or the hand in sign language so as to generate a linguistic utterance. Understanding language is one of the major integrative acts at which the human brain excels. The brain must integrate different kinds of language representations, such as semantic, syntactic, phonological knowledge of words, and discourse information, in real time during the process of understanding and speaking. It is thus to the brain in action that electrophysiologists turn for answers to fundamental questions about the nature of language representations and operations on them, and about the relationships among language and other cognitive processes.

There are more than 4,000 languages in the world. However, it is believed that their comprehension and production can be analyzed similarly in terms of a number of different kinds of representations (such as semantic, syntactic, and phonological knowledge) and a set of seemingly rule-based operations on these representations (such as accessing phonological, syntactic, and semantic information about words and sentences). The questions addressed by psycholinguistics examine what operations are performed on which representations at what point(s) in time. Psycholinguists argue about whether certain language abilities result from dedicated insular brain areas each specialized for specific kinds of linguistic representations and processes (modular approach), or whether these abilities are more accurately described in terms of interactions among different linguistic levels distributed across multiple brain regions (interactive or parallel distributed processing approach). They also argue about when in the processing stream the various representations make contact with each other, if ever. More recently, in addition to linguistic and psycholinguistic methods, various neuroimaging techniques have been used to investigate where, how, and when language processing takes place.

Functional brain imaging techniques differ widely in their ability to delineate separate physiological processing events, and to map these events onto both their spatially defined neuroanatomical substrates and their temporally defined place in the causal chain that guides thought and behavior. Those that depend on physiological changes related to energy metabolism in the brain (such as positron emission tomography [PET] and functional magnetic resonance imaging [fMRI] have illuminated important anatomical substrates of language processing. However, these metabolically based functional imaging techniques have not been as successful in elucidating the orchestration of these areas because they occur on the order of at least 2 seconds—much too slow to reflect changes crucial to the language processes that occur on the order of tens to a few hundreds of milliseconds. Because they depend on blood flow, PET and fMRI measures do not have the temporal resolution to index neural changes occurring for less than a second. The scalp-recorded electrical or magnetic fields produced by the brain, on the other hand, have had fewer applications in terms of anatomical mapping but enjoy a much higher temporal resolution (in milliseconds instead of seconds). Techniques with millisecond resolution, such as event related-brain potentials (ERPs) and their magnetic counterpart, the magnetoencephalogram (MEG), can be used to track the availability of different sorts of linguistic information and the temporal course of their interactions, and, thereby help to reveal how language processing unfolds over time.

AN INTRODUCTION TO ERPs

The general approach of electrophysiological studies assumes that (a) language processes take place in different anatomical and physiological substrates, (b) engagement of these substrates generates distinct patterns of biological activity (in this case, ion flow across neural membranes), and (c) these patterns (in this case, of electromagnetic activity) can be recorded inside and outside the head. The remainder of this chapter provides illustrations of how this type of research is carried out. We begin with an introduction to the ERP technique. We then review some ERP data concerning what goes on in the brain/mind of the language comprehender and the language producer (see also Brown & Hagoort, 2000; Brown, Hagoort, & Kutas, 2000; Kutas & Van Petten, 1994; Osterhout & Holcomb, 1995).

The Talking Cell

Comprehending and producing language are brain functions that require the coordinated activity of large groups of neurons. Neurons (nerve cells) have a sophisticated electrochemical system for communicating with each other. At rest, each neuron has a difference in its electrical charge due to an uneven distribution of positive and negative ions inside and outside of it. This is known as the resting potential. This potential can be disturbed by a change in the permeability of the membrane to certain ions, such as occurs when a cell is stimulated. The consequence of stimulation is an all-or-none action potential or spike that travels down an axon (a neuron's output). This spike signal is passed onto the next neuron via the release of neurotransmitter, which is a chemical substance that affects the next neuron by diffusing across a space between neurons, known as the synapse. Some neurotransmitters alter the permeability of the receiving cell's membrane to certain ions (i.e., altering the shape of proteins in the cell's membrane so as to allow some ions to get in and to keep others out), thereby increasing the likelihood that it will fire, whereas others have the opposite effect. These voltage-changes are reflected in the receiving cell in excitatory postsynaptic potentials (EPSPs), which increase the likelihood that the cell will fire, and inhibitory postsynaptic potentials (IPSPs), which decrease the likelihood that the cell will fire. Any given cortical cell receives hundreds of synaptic inputs, mostly on its dendritic arbor, a branch-link structure that receives information from other neurons, or on its soma (body). The postsynaptic potential generated at each of these synapses is not large enough to cause the cell to fire; however, these postsynaptic potentials sum in space and time. When the sum surpasses a neuron's threshold it will fire, thereby sending the signal via its axon to the next neuron, and so on.

The neural communication that underlies human communication thus involves the flow of charged particles across the neural membrane, which generates an electric potential in the conductive media both inside and outside the cell. These current flows across neuronal membranes are the basis for the electrophysiological recordings at the scalp. The electric potential at any given moment depends on the membrane currents only at that moment. What this means is that it is possible to monitor the neurons talking to each other, as it were, on a moment-by-moment basis.

It is possible to measure this activity by placing at least two electrodes somewhere on the head and recording the voltage difference between them. These measurements are much more sensitive to the currents at this receiving end (the EPSPs and IPSPs in the dendritic arbor of a cell) than to the spike generated down the axon that is used to communicate with the next cell. What we see at the scalp is the sum of these EPSPs and IPSPs for many neurons acting in concert in like manner. In fact, much of the activity seen at the scalp is probably that of the pyramidal cells of the neocortex because their dendritic arbors, when activated synchronously, tend to align in the same orientation thereby allowing the summation of their activity to be observed as a signal at the scalp (Kutas & Dale, 1997; Martin, 1991; Nunez, 1981).

Many Cells Telling Each Other What They Saw, Heard, Thought, or Felt

The brain is particularly sensitive to transient changes. Thus, if a picture, for example, of an aardvark were suddenly to appear in front of your eyes, your brain would process this patterned visual input, as it would a word, and so on. Cells in the parts of the brain that process visual information (i.e., primary & secondary visual cortices) and are involved in object recognition (i.e., inferotemporal cortex) would fire and within a few hundred milliseconds you would "know" that you had seen an animal, whether or not you knew exactly which one it was. At the same time, cells in other areas of the brain also would fire (see Mason & Kandel, 1991). Perhaps a little later you might come to realize that you once knew the name of this type of animal and would actively search your mind for it. You might fail, even if you knew that its name has two syllables and rhymes with "ark". On another occasion you might simply have uttered "aardvark" almost immediately. Whatever the case, there would be a flow of neural activity that could be traced from the retina through the visual pathways and into the higher areas of the brain and back and forth, (see e.g. McCarthy, Nobre, Bentin, & Spencer, 1995; Tanaka, 1996).

If one of these scenarios had taken place in an experimental laboratory setting, it would be considered an event or trial, and the electrical activity synchronized in time to the picture's appearance would be the evoked response (EP) to that event. The brain's response to such an event is what an electrophysiologist wants to measure so as to track what the brain does with the event. In so doing we can find out to which stimulus, cognitive, and response parameters the brain is sensitive. In addition, we can look at *when* in the temporal course of the event under investigation the brain reacts. However, the response to a single event is quite small relative to all the other ongoing electrical activity in the brain as well as in the eyes, muscles, and heart. We can, however, take advantage of the fact that the specific activity we want to measure is locked in time to the event we are interested in. Accordingly, we can record the evoked response to many such events (either physically or conceptually similar) and average them. At any given moment the electrical activity that is not time-locked to the event of interest is just as likely to be positive as negative, so with enough events, this "noise" from the various trials cancels out. What remains is the average EP or event-related brain potential—the ERP, as shown in Fig. 7.1 (for a detailed introduction on ERP see Coles & Rugg, 1995; Kutas & Federmeier, 1998; Kutas & King, 1996; Kutas & Van Petten, 1994).

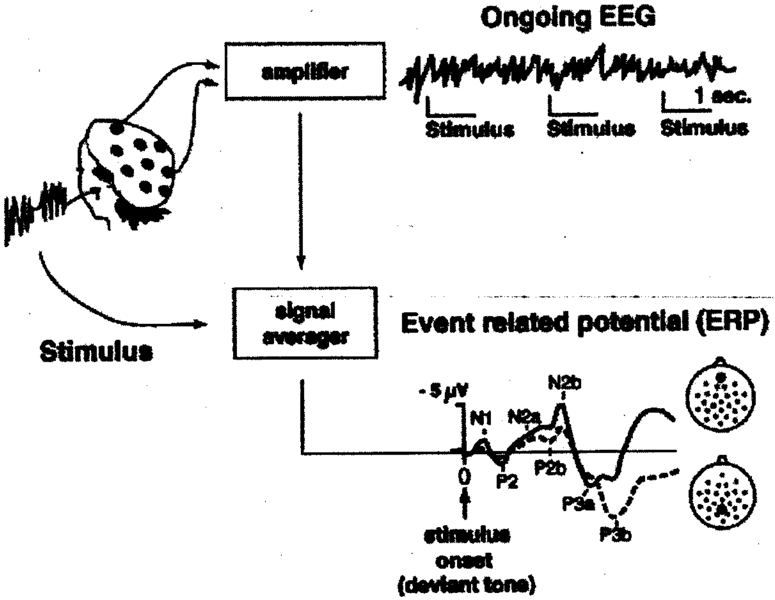


FIG. 7.1. Derivation and component structure of the event-related potential (ERP) to a deviant stimulus. The analog-recorded electric potentials at the scalp are shown as the ongoing electroencephalogram or EEG (top) is amplified and digitized. The ERP is generally too small (amplitudes of about 5–20μV, where 1V is 1 millionth of a volt; by comparison consider that an average flashlight battery is 1.5μV) to be detected in the EEG (amplitudes of about 100μV), and thus requires computer averaging over many stimulus presentations to achieve adequate signal-to-noise ratios. After averaging, time-locked to the onset of the stimulus, the ERP emerges as a waveform with a variety of positive and negative peaks (components). The solid line represents recordings from a midline frontal site and the dashed line the recording from a midline parietal site. Circles on the head icon represent electrode locations. Larger gray circles represent the electrode sites for which the average waveform is displayed; Negative is plotted upwards in this and all subsequent figures; potentials above the baseline are negative-going relative to activity prior to the stimulus whereas those below the baseline are positive going. Whether components are negative or positive at the scalp is a function of the location of the electrodes used for the recording and thus does not have any significance per se (after Näätänen, 1982, and Hillyard & Kutas, 1983). Note that a stimulus could also be a picture that has to be named, or a specific word in a sentence that has to be read or heard. Linguistic stimuli usually elicit specific ERP components that occur later in time than those shown here. Language related components (such as N280, N400, P600/SPS, LRP, N200) are described in more detail later in this chapter.

The Cells' Gossip Creates Waves

We record the electroencephalograph (EEG) at multiple sites on the scalp, each marked by a circle on the head icon in Fig. 7. 1. The EEG activity at each of these locations is averaged to yield an average ERP for that recording site. The average ERP is typically looked at as a waveform—a plot of the variations in voltage over time relative to the stimulus onset. There is one ERP waveform for each recording site. Such a waveform consists of a series of positive and negative-going waves (relative to baseline activity prior to event onset).

These waveforms can be analyzed in terms of their morphology (shape), the latency in time of their peaks, or the onsets of positive or negative-going waves, amplitude (size) of their peaks, distribution across the scalp, and duration of salient waveform pattern. The tradition is to measure the peaks, although there is nothing special about peaks; in principle, every moment of the waveform could be equally informative as it merely reflects neural activity at that instant.

Until quite recently, electrophysiological investigations of language have focused on relatively fast (high frequency), transient responses elicited by some "linguistic" event (e.g., picture or written or spoken word in a list or within a sentence); more recently, much slower potentials that develop across sentences and clauses have also been monitored.

Written words, spoken words, visuo-gestural words as in American Sign Language, and pictures each elicit a characteristic pattern of waves also known as components. The components are labeled in terms of their polarity as either negative (N) or positive (P) and in terms of their order of appearance (e.g., N1 first negative peak, N2 second negative peak, etc.) or in terms of their typical or actual latency (N100 at 100 msec, or N120), relative to stimulus onset. The initial components (e.g., P1, N1) are very sensitive to stimulus parameters (intensity, duration, spatial frequency, location in visual field) and attentional manipulations and are often seen as obligatory responses to stimuli. The later components are more task dependent as they show less sensitivity to physical stimulus parameters and greater sensitivity to variables that are neither strictly sensory nor strictly motor; they are optional depending on how the stimulus or event is processed.

When visually presented words are the events of interest, a typical average ERP may include P1, N1, P2, and other components, that are occasionally labeled by their proposed functional significance or scalp location; thus, FSN is frequency sensitive negativity, LRP is lateralized readiness potential, SPS is syntactic positive shift, CEN is clause ending negativity, and LAN is left anterior negativity.

Specifically, the FSN (referred to as LPN within the context of words) is a negativity over the left side of the front of the head occurring between 250 and 400 msec after a word's onset with a latency depending on the eliciting word's frequency of usage. The P2 component between 150 and 220 msec (sometimes together with a P3) occurs a little later and varies with the amount of attention directed at the features of the eliciting event. Note that these early components are elicited by nonlinguistic visual and auditory stimuli as well. However, especially the FSN can vary with the frequency of daily usage of words, and because it does so, it seems to be informative for linguistic processing (see the later section Representation and Processing Speed: The LPN for more details). The N400 (250–450 msec) is sensitive to a word's (or picture's) analysis at a semantic level. The SPS (or P600) varies with aspects of syntactic processing. The N400–700 is a later, slow potential seen prominently over the front of the head, that has been linked to anticipation of upcoming syntactic constructions (such as anticipation of a prepositional phrase following a preposition) in sentences (for review, see Hillyard & Picton, 1987; Kutas, Federmeier, Coulson, King, & Münte, 2000; Kutas & King, 1996; Osterhout & Holcomb, 1995). We discuss some of these in greater detail later.

Is Component X = Component X?

Before reviewing some specific examples of how ERP measurements are used to make inferences about various psycholinguistic issues, we wish to bring up one of the more difficult aspects of this type of research, namely, that of component identification. Is the negativity observed in one experimental condition the same as that observed in another condition? The answer, of course, depends on what one means by "the same" (reflection of same neural generator, same functional process). To begin, it is next to impossible, even for an experienced ERP researcher, to be shown a plot of an ERP waveform and asked to interpret it without more information. It is not even clear that one could say with certainty that the response was from a human. Given a plot of waveforms across the scalp surface of a human, the best one can do is to guess the modality (visual, auditory) of the eliciting stimulus. But beyond this, deciphering the waveform is difficult because for isolated events, the typical ERP consists of activity in a time window of a second or two, wherein there are a number of positive- and negative-going waves. The presence of large late potentials (300 msec plus) is often a sign of some "cognitive" processing, but it could also be a sign of drowsiness or that the person was asleep. A 30-year history of ERP research shows that ERPs are best interpreted in the context of the experimental conditions in which they were collected. ERP research has enumerated the types of ERP effects that are routinely seen in response to certain types of manipulations of attention, decision making, matches, mismatches, improbable events of various types, semantic variables, syntactic variables, how words look, how words sound, pseudowords, items in and out of context, encoding, and so on (e.g., Rugg & Coles, 1995).

Within each experiment or task, the safest reading of the ERPs comes out of contrasts between two or more waveforms, i.e., the effect as a difference of two experimental conditions. For example, although one might know that an unexpected word in a sentence context will elicit a negativity peaking at around 400 msec, one feels safer labeling it an N400 if the ERP it is a part of can be compared to that of a control word. The control word usually should be of the same part of speech (e.g., noun or verb) and it should have approximately the same within modality frequency of daily usage as the target word. Furthermore, both the control word and the target word should occur in the same position in the sentence. The two words should differ only in one experimental dimension, such as whether or not the word makes sense in the sentence (i.e., semantic expectancy). Moreover, one could feel on safer ground if the waveform has certain characteristics that one typically observes for an N400: a negativity that starts around 200 msec, lasts for a few hundred milliseconds, is larger posteriorly than anteriorly, and is larger over the right than the left hemisphere. However some N400s peak at 500 ms (as in elderly individuals or sentences presented at fast rates; see King & Kutas, 1995c) and some N400s are not as posterior or as lateralized as the one initially described for semantic violations. Yet they are considered N400s nonetheless. Moreover, not all negativities peaking at 400 msec are N400s. Would that it were that simple!

Part of the problem in identifying components stems from the inability to locate the neurons that are responsible for an ERP pattern. It is impossible to determine what subset of neurons generated some particular pattern of potentials at the scalp if the only information available is the pattern itself. In principle, the same pattern at the scalp could be created by various combinations of different neural generators, because the potential fields of active neuronal generators sum linearly. Thus, in the same way that one cannot tell from the number 7 how the total came about (e.g., 6 + 1, 5 + 2, 4 + 1 + 1+ 1, 8–1, etc.), the brain sources for the scalp potentials remain a mystery during the interpretation of a component at the scalp. We would be safe if we knew that only one generator were active at a time, because this generator would have a spatial signature at the scalp each time it was engaged. However, from what we know of how the brain works, this is highly unlikely. Usually, more than one generator is involved in complex cognitive tasks. Intracranial recordings from electrodes in the brains of epileptic patients (McCarthy et al., 1995), and on the scalp of individuals with various kinds of brain damage can help to localize a component's generators as can magnetic recordings combined with various modeling techniques (Dale & Sereno, 1993; Dale et al., 2000).

Although intracranial recordings are usually made prior to neurosurgery in individuals with seizure activity (and may thus be abnormal), in many cases, the implanted electrodes may be closer to the neural generators of the component in question. Various aspects of the recorded potentials such as its polarity and its polarity relative to those of potentials at nearby electrodes (same or opposite) as well as the relative amplitudes of potentials at electrodes nearby versus farther away all can be used to infer the likelihood that the generator of the recorded potential is close by. Likewise, although a compromised brain may yield uninterpretable brain activity because it is damaged, whether or not, and if so how, damage to a particular brain region influences the potentials at the scalp can be used to infer whether that area is essential for, or at least involved in, some aspect of the generation of modulation of the component of interest.

In summary, the ERP is a biological tool that can be used to measure a variety of cognitive processes. It is essential to interpret the ERP component in the context of the experiment and its specific manipulations. The experimental comparison does not reveal the anatomical locus of a component but does constrain the likelihood that it is the same as another component with the same functional characteristics. In addition, because of the ERP's high temporal resolution it is especially well suited to address issues concerning timing and interaction in ~~high-speed processes, such as language. Next we discuss how~~ ERPs are used to investigate language comprehension.

FROM THE EARDRUMS TO THE MEANING: ERPS IN COMPREHENSION

The recognition of spoken language begins with the extraction of acoustic and phonetic information from the speech signal. This is a nontrivial problem, given that the acoustic signal includes no obvious cue as to where a word begins or ends (for a review see Lively, Pisoni, & Goldinger, 1994). What information then does the listener use to extract meaning from an essentially continuous acoustic stream? Are there units of perception, and if so, are they acoustic-phonetic features (such as the length of vowels), phonemes, syllables, and/or prosodic patterns? Reaction time studies show shorter recognition latencies for "well-" as opposed to "ill-formed" patterns based on each of these units of analysis, thereby giving them some psychological reality (for a review see Altmann & Shillcock, 1993; Caplan, 1992; McQueen & Cutler, 1997). But there is still no consensus on whether the brain actually categorizes acoustic input in these ways nor about how these units might feed into or interact with higher order cognitive processes such as meaning integration.

One assumed source of meaning is the mental "lexicon"—an abstract store of knowledge about words. Psycholinguists commonly use the term *lexical access* as a metaphor for the process of looking up or activating language-related information in this lexicon. The fastest way of looking up the German word "Erdferkel" in a German-English dictionary is to use the alphabetic coding system. So doing reveals that "Erdferkel" is the German equivalent of an "earthpig" or 'aardvark'. Besides phonological information, syntactic information becomes available, such as that the word is a noun. Furthermore, for a native English speaker, the translation would automatically provide access to the word's denotative meaning. Thus, you may find that an aardvark is a large burrowing nocturnal mammal—an animal that has an extensile tongue, powerful claws, large ears, a heavy tail, and an appetite for termites. If you are a student in the cognitive science department at the University of California at San Diego you may also be reminded of the fact that it is the name of the department's sports teams.

Although there is consensus that word knowledge is stored, there is less agreement on exactly what information about words is stored in the mental lexicon, the internal structure of the store, how it is used during comprehension or production, or how it is implemented in neural tissue. It has been suggested that, like a real dictionary, the mental lexicon holds different types of information about words, such as phonological information (maybe in term of cohorts; see Colombo, 1986), semantic information (in terms of networks or category relations; see Collins & Loftus, 1975; Miller & Fellbaum, 1991; Saffran & Sholl, 1999), and syntactic information, although none necessarily in a single location. In fact, the same "word" may be represented multiply along different dimensions, which normally come together when that "word" is accessed. Presumably each of these dimensions is structured because this aids error-free access. A fast, error-free access is needed, because in a typical conversation a normal speaker produces about five to six syllables per second (Deese, 1984), and up to150 words per minute (Maclay & Osgood, 1959), and a listener has to segregate the incoming speech stream very quickly in order to keep up with the speaker.

Reaction-time studies indicate that before a speech sound is recognized as a particular word, several lexical candidates consistent with the available input become activated (accessed); this cohort is progressively winnowed until only one candidate that is consistent with the acoustic input is selected as the word heard (Marslen-Wilson, 1987, 1990; Marslen-Wilson & Welsh, 1978; Zwitserlood, 1989). At issue is whether or not phonological, syntactic, or semantic information is involved in reducing the initial cohort. Interactive models (such as TRACE; see McClelland & Elman, 1986) say semantic and phonological information influences speech perception whereas autonomous models (such as SHORTLIST; see Norris, 1994) say semantic information does not influence speech perception. As currently implemented, both types of models can account for lexical effects in a variety of experimental tasks, thereby leaving the question of autonomous versus interactive processing still open (see McQueen & Cutler, 1997). The need for convergent data from other methods, such as from ERP investigations of speech processing, is obvious (see Van Petten, Coulson, Rubin, Plante, & Parks, 1999).

Because of its exquisite temporal resolution, the ERP can be used to track the time course of the brain's sensitivity to various information types—phonological, semantic, syntactic—in the acoustic stream. By the time an effect of a variable is evident in the ERP, it must have been registered—hence, the onset latency of the ERP effect provides information about when specific cognitive processes are performed. At times the pattern of ERPs recorded also can be revealing about the extent to which various information types are or are not integrated. An added benefit of the ERP technique is that no extra task (such as categorization or lexical decision in reaction time experiments) above and beyond listening, reading, or comprehending needs to be imposed to garner a dependent variable. On the pathway from the eardrums to the mind, we address ERPs in phonological processing first and than delve more deeply into the mind by addressing semantic, syntactic, and discourse processes.

Is the ERP Sensitive to the Time Course of Phonological Access?

If ERPs are to be useful in studies of the sound patterns of human language, we first need to know whether or not they are sensitive to phonological information. There are several ~~reasons why the ERP at the scalp may not show sensitiv~~ity to any particular variable, in this case, phonological information. For instance, it may be that phonology is processed in a brain area whose activity is not readily seen at the scalp. This could be because the active regions of the neurons involved in the ERP's generation are aligned so that the potentials cancel each other (as in a closed field). This could also be because the phonological processing does not occur in the same temporal synchrony with the eliciting stimulus across trials. However, if we find that some parameter of the scalp-recorded ERP does vary with phonological information, then we can use the timing of the effect as an estimate of the upper limit on when the brain must have registered the information. Thus, we can use the ERP to ask when phonological information becomes available during natural speech processing. We may also use the ERP's sensitivity to phonological information to examine a controversial aspect of theories of lexical access—namely, whether phonological processing occurs prior to and independent of semantic processing, as suggested by an autonomous approach, or whether semantic information can influence phonological encoding, as suggested by an interactive approach.

Rhyme Time: When in Comprehension Does Phonological Information Become Available?

The words "cat" and "cab" share the same initial phonemes. "Cat" and "hat," on the other hand, share word-medial and word-final phonemes; that is, they rhyme. When does a listener notice these relationships, and is the ERP sensitive to the perception of these phonological relations? And is the onset relation noticed earlier than the rhyme relation, as might be expected given the serial nature of acoustic input? Praamstra, Meyer, and Levelt (1994) used ERPs to examine this question by presenting participants with pairs of spoken words that had either an onset relation, rhyme relation or no phonological relation (e.g., "cat"–"sun"). After a slight delay subjects indicated whether the stimulus was a real word or not. The ERP of interest was time-locked to the beginning of the second stimulus.

As can be seen in Fig. 7.2, all acoustic words elicited a similar waveform with an early negativity at around 100 msec (N1) followed by a large negativity peaking at around 400 ms. The late negativity was largest in amplitude for unrelated words; it was reduced in amplitude for both types of phonologically related second words. The reduction was evident early, between 250 and 450 msec relative to word onset for the onset relation, and, later, between 450 and 700 msec for the rhyming relation (for similar ERP rhyming data, see Barrett & Rugg, 1990; Rugg, 1984a, 1984b; Rugg & Barrett, 1987).

Because the rhyme and the onset versions were carried out in separate experiments using different materials, the timing differences must be interpreted with caution. In any case, however, the results show that the ERP is sensitive to phonological processing. Moreover, if we assume (as the authors did) that the same ERP component is varying in both conditions, then the results indicate that its latency is sensitive to the time course of phonological encoding (showing an early effect for word onset, and a late effect for rhyme relations). The data show that phonological encoding takes places serially.

Furthermore, the observed phonological effect is similar in timing (between 200 and 600 msec) and scalp distribution to the N400 component, usually observed in semantic tasks (Pritchard, Shappell, & Brandt, 1991). What might this similarity mean? If the phonological N400 is the same as the semantic N400, one could argue that phonological and semantic processes are not independent. However, even if this negativity is not an N400, the data indicate a temporal overlap in the processing of phonological and semantic information. Whatever the case turns out to be, the described experiment illustrates how the fine-grained temporal aspects of the ERP make it an excellent tool for investigating the time course of phonological processing, which is closely aligned in time and perhaps interactive with semantic processing.

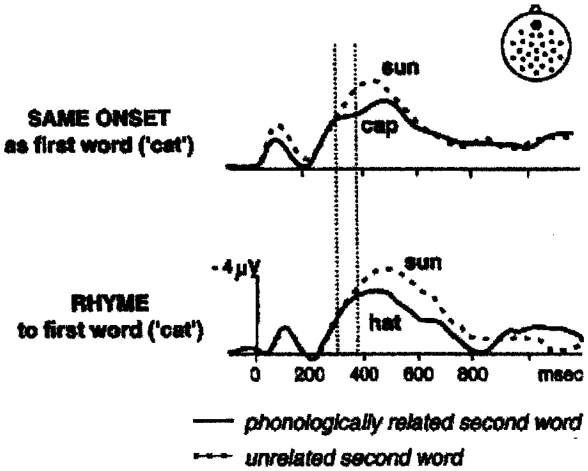


FIG. 7.2. Comparison of the grand average ERPs elicited by a second word of a phonologically related and unrelated spoken word-pair (the same 24 participants in all conditions; 40 trials per condition). The top panel shows an early phonological effect when the second word shares the same onset phonemes with the first word. The bottom panel shows a later phonological effect when the second word rhymed with the first, that is, shared final phonemes. (Adapted from Praamstra et al., 1994, with permission).

From other experiments like this we know that the ERP is also sensitive to (a) identity relations, so that processing "cat" after "cat" is different from "cat" after "sun" (Doyle, Rugg, & Wells, 1996; Rugg, 1985; Van Petten, Kutas, Kluender, Mitchiner, & McIsaac, 1991); (b) morphological relations, so that "jump" after "jumped" is different than "jump" after "look" (Münte, Say, Clahsen, Schiltz, & Kutas, 1999); and (c) semantic relations, so that "cat" after "dog" is different from "cat" after "ink" (Holcomb, 1988; Kutas & Hillyard, 1989). The phonological, morphological, and semantic effects all occur by about 200 msec. So although it is not a direct empirical test of the question we raised about the role of meaning in phonological processing, these data are more in line with parallel then serial processing models of phonological, morphological, and semantic information during comprehension.

The Brain's Response to Meaning: The N400

The mind's extraction of meaning has been examined not only within word–pair tasks but also using "violation" paradigms. Our brains are very sensitive to violations of meaning. Specifically, a written, a spoken, or a signed word that does not make sense relative to its context elicits a large negativity between 200 and 500 msec that peaks around 400 msec (Kutas & Hillyard, 1980a, 1980b, 1980c). Even a semantically anomalous picture seems to elicit an N400–like response. In such studies, sentences are presented visually to volunteers one word at a time for comprehension. The sentences might vary, depending on the degree of expectancy of the final word, as in the following example:

He was stung by a bee.	(expected ending)
He was stung by a hive.	(unexpected, but semantically related)
He was stung by a mile.	(unexpected and semantically unrelated)

The ERPs to these final words (for an average of 25 words per condition), are depicted in Fig. 7.3. The expected word elicits a positivity between 200 and 500 msec, the semantically anomalous word elicits a large N400, and the anomalous but semantically or associatively related word elicits an N400 of intermediate amplitude (Kutas & Hillyard, 1980a, 1980b, 1980c, 1982; Kutas, Van Petten &

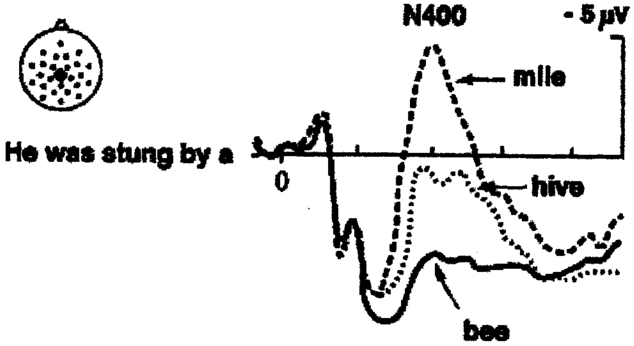


FIG. 7.3. Grand average ERPs elicited by visually presented sentence–final words, showing a positivity between 250 and 500 msec (solid line) for a predictable word, and an N400 between 200 and 500 msec for a semantically anomalous word (thick dashed line). When the final word is semantically incongruent but semantically related to the expected final word (dotted line), it elicits an N400 of intermediate amplitude (After Kutas and Hillyard 1984), with permission.

Besson, 1988; for a review see Kutas & King, 1996 and Kutas & van Petten, 1994). Fortunately for its utility as a tool for investigating semantic processing, N400 elicitation is not driven solely by semantic anomalies. In fact, in a sentence context all words seem to elicit some N400 activity, with the amplitude determined by how expected a word is and thus how readily it can be integrated with the current context at a semantic level. In the absence of context, N400 amplitude is determined by word frequency (larger for low-frequency words according to Francis & Kucera, 1982, among others), concreteness (larger for concrete than abstract words), and other properties of the words. With minimal context such as in a word pair, the N400 to the second word is reduced by repeating the same word exactly or by a word that is semantically related. Within a sentence, with all else held constant, the amplitude of the N400 to any content (meaning–bearing) word such as an adjective, adverb, noun, or verb becomes smaller and smaller the further into the sentence it occurs. Studies using words in semantically anomalous sentences (meaningless, but syntactically correct sentences, such as "Colorless green ideas sleep furiously") show no such reduction in N400, regardless of the word's intrasentential position. This suggests that it is the semantic rather than syntactic constraints that conspire to reduce the N400 in normal prose.

The N400 occurs within 200 msec after presentation of the critical word, thereby supporting theoretical models of sentence processing that assume relatively immediate online integration of a word's meaning into sentence context (Gernsbacher & Hargreaves, 1988; Just & Carpenter, 1980). The N400's timing does not support models which propose that word meanings are buffered for use at phrase boundaries, clause boundaries, or the ends of sentences rather than analyzed on a word-by-word basis with respect to the immediate context (see Fodor & Bever, 1965; Garrett, Bever & Foder, 1966; Just & Carpenter, 1980; for a review, Kutas & Van Petten, 1994).

Data from several studies show that the important context for modulating N400 amplitude is not just a related word earlier in the sentence, or the many words of a sentence, but also that of the larger context of the discourse of which a sentence may be but a part. As single sentences, both "The aardvark went quickly into its burrow," and "The aardvark went slowly into its burrow" are equally plausible and the words within them should elicit about the same level of N400 activity. However, put into a larger discourse context, such as, "It was a quiet summer day. The aardvark was surprised by the sudden appearance of the tiger and went ... " the two adverbs (quickly, slowly) are no longer equally expected. If discourse information comes into play relatively early during sentence processing, then one might expect a larger N400 to the word "slowly," because it is less expected in the context; this is what Van Berkum, Hagoort, and Brown (1999) found for similar materials in Dutch (see Fig. 7. 4).

Whatever else this might mean, such results show that discourse-level information can influence how words in a sentence are processed. Moreover, discourse-level effects appear to come into play about the same time that a single

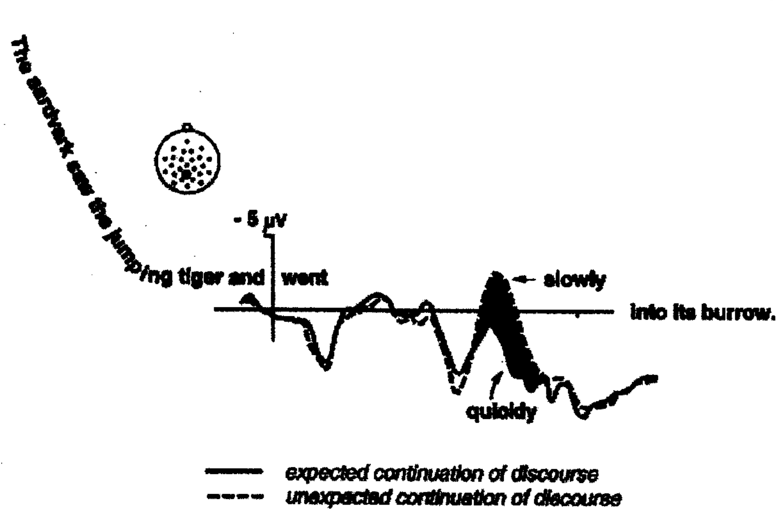


FIG. 7.4. Grand average ERPs (24 participants, 40 trials per participant) elicited by three words in a sentence; the second word is either an expected or an unexpected adverb, where the expectancy is based on discourse level information. The solid line shows the ERP to an expected continuation of a sentence in the discourse. The dashed line represents an unexpected continuation. The shaded area depicts the discourse level effect on N400 elicited by the unexpected adverb. After Van Berkum, Brown, and Hagoort, (1999), with permission.

related word would have its effect or that prior words in a sentence would have their effects. These results are clearly at odds with a serial view of processing that makes a clean separation between a word's processing and the larger sentential or discourse context with which it has to be reconciled. In summary, the N400 is a very robust index of semantic processing at the lexical, sentential, and discourse levels.

Representation and Processing Speed: The LPN

Although we do not yet know exactly how words are extracted from the speech signal, we can nonetheless ask whether words, once detected as such, differ from each other, in either their representation or their processing. Are nouns, because they refer to objects, and verbs, because they refer to actions, differentially represented in the brain (e.g., Pulvermüller, 1996)? Is the brain's response to nouns and other meaningful, content-bearing words different from its response to function words, such as articles, conjunctions, prepositions, auxiliaries, which tend to have less meaning and to serve the function of relating the content words to each other? From a linguistic point of view, different parts of speech clearly do play different functional roles, and thus some have argued that indeed they are stored in different brain regions and, at least for content versus function words, are accessed from the mental lexicon in qualitatively different ways (as proposed by Swinney, Zurif, & Cutler, 1980; see also Patterson & Shewell, 1987; Shillcock & Bard, 1993).

On the face of it, ERPs to different word classes do differ. The responses to function and content words differ from one another, as do the responses to nouns versus verbs and pronouns versus articles, among others. For example, open class words, which are content words, have larger P200s and N400s than function words when both types are embedded in a sentence (King & Kutas, 1995a; Kluender & Kutas, 1993; Neville, Mills, & Lawson, 1992; Van Petten & Kutas, 1991). In fact, no one denies that different lexical classes are associated with different ERP patterns. They do, however, disagree over what this means about how their members are represented in the brain and/or how they are accessed. It is difficult to answer this question because content and function words vary in important ways, such as word length and word frequency, which are in and of themselves known to have big effects on a word's processing.

For example, both reaction time and eye movement testify to the fact that longer words take more time to access than shorter words and that frequently used words are understood and produced more quickly than rare words (Jescheniak & Levelt, 1994; Just & Carpenter, 1980). These differences alone could account for the observed differences between the ERPs to content and function words, as function words are typically much shorter and of much higher frequency than content words (Gordon & Caramazza, 1985; Thibadeau, Just, & Carpenter, 1983). In fact, we have found that frequency does account for one of the proposed ERP differences between the two word classes (King & Kutas, 1995a, 1998). Contrary to the suggestion that there is a negative potential around 280 msec (N280) that is a marker for closed class words, we find that taking into account the frequency of a word reveals that the ERPs to all words include a negativity at left frontal recording sites. Thus, regardless of lexical class, the ERPs to all words contain a negativity somewhere between 250 and 400 msec, whose latency varies with a word's frequency of usage (See Fig. 7.5.)

On average, closed class words show this negativity (called the lexical processing negativity or LPN, or frequency sensitive negativity or FSN, indicating the possibility that the negativity may not be specific to words) at 280 msec and open class words, which are longer and lower frequency, show it about 50 msec later at 330 msec. This index of a word's frequency of usage is present to all words as they are read naturally for comprehension; no other overt response is needed. Even if the LPN/FSN does not reflect lexical access from the mental lexicon (because it might reflect other processes involved, such as working memory), it is strongly correlated with the process of lexical access. Thus, the LPN/FSN can be used as a dependent variable in investigations of how quickly or easily words are retrieved.

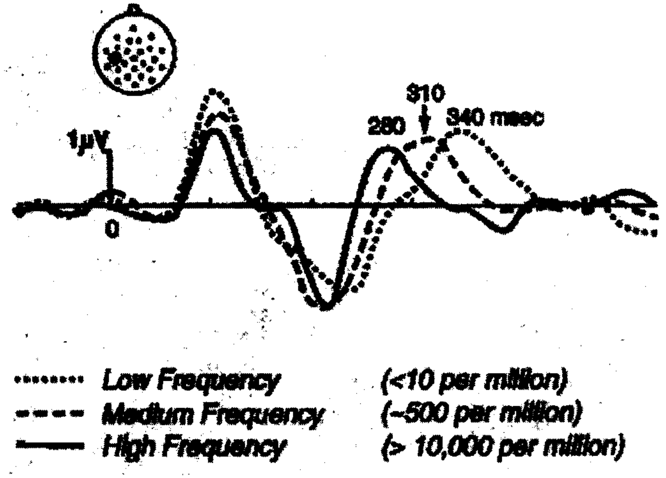


FIG. 7.5. Grand average ERPs elicited by words of different frequency of usage (bandpass–filtered, 4–20 Hz). High frequency words (solid line) elicit a negativity peaking at about 280 ms after word onset. This peak latency is earlier than for medium frequency words (dashed line, 310 msec) and low frequency words (dotted line, 340 msec). The negativity is called the lexical processing negativity or LPN, or even more generally the frequency sensitive negativity or FSN. (After King and Kutas, 1998), with permission.

WHEN SYNTACTIC VIOLATIONS DIFFER WHAT DOES IT MEAN?: THE SPS/P600

Until recently, most of the neuroimaging work on language processing has focused on the processing of single words, usually as part of word pairs or a longer list. But language is much more than a string of isolated words. Most of our communicative acts occur in sentences or beyond, as in discourse. Linguists tell us about the hierarchical structure of utterances—that is, what orders of words in a sentence are acceptable and which are not, as well as the grammatical roles that these words play. Psycholinguists propose various strategies that describe how a comprehender determines the proper structural analysis of a sentence—that is, how he or she parses the sentence. Many of the more recent ERP studies of language have been designed to test among alternative theories of parsing (see Pullum & Scholz, this volume; also chap. 5, Fodor, 1989, 1995; Garnsey, 1993; Garnsey, Tanenhaus, & Chapman, 1989; Garrett, 1995). These investigations capitalize on the observation that ERPs are sensitive to manipulations of at the level of syntax (relations between words in a sentence) and the nature of the effect differs qualitatively from that observed to more lexico–semantic manipulations.

In search of the functional significance of the N400 component, Kutas and Hillyard (1983) found that a syntactically or grammatically incorrect word such as a singular verb following a plural noun (e.g., "turtles eats") did not elicit a large N400, like a semantic anomaly, but rather small fronto–central negativity together with a small late positivity. Ten years later two laboratories independently identified a late positivity that is reliably elicited by a variety of syntactic violations. This positivity, variously called the syntactic positive shift (Hagoort, Brown, & Groothusen, 1993) or P600 component (Osterhout & Holcomb, 1992), can occur anywhere between 300 to 800 msec postword onset and is widely distributed across the scalp. Figure 7.6 shows the contrast between syntactically correct and incorrect sentences, wherein the violation is the grammatical number marking on the verb ("My pet aardvark prefer/prefers to eat potatoes").

As can be seen in the figure, this morphosyntactic violation elicits a positivity, large over posterior sites, that starts at around 500 msec after the violating word was presented and lasts for 300 msec or so. Similar effects have been noted for other violations including reflexive–antecedent gender agreement (e.g., "The momma aardvark sees himself as a potato lover"), reflexive-antecedent case agreement, phrase-structure violations (e.g., "The aardvark was fascinated by the emotional rather response of its mother"), constraints on the movement of sentence constituents ("What was a proof of criticized by the scientist?"), and verb subcategorization. Similar effects have been observed for violations occurring in written and spoken sentences in English, Dutch, German, and Finnish (e.g., Friederici, Pfeifer, & Hahne, 1993; Hagoort & Brown, 2000; Osterhout & Holcomb, 1993). Importantly, the P600 is seen whether the subject's task is to make an acceptability or grammaticality judgment or merely to read or listen to the sentence (for review see Osterhout, McLaughlin, & Bersick, 1997).

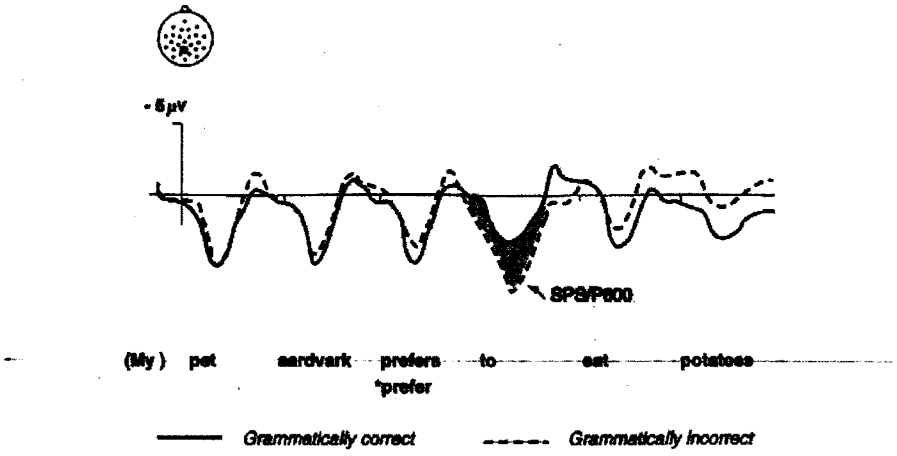


FIG. 7.6. Grand average ERPs elicited by a syntactic violation of subject–verb–number agreement. The solid line shows the ERP to syntactically correct sentences, the dashed line to syntactically incorrect sentences. The shaded area indicates the effect of this violation, known as the syntactic positive shift (SPS), or P600. After Hagoort, Brown, and Groothusen (1993), with permission.

The presence of P600 across a wide variety of grammatical violations has been used to argue for its syntactic sensitivity, although it also makes it difficult to pin down exactly what aspect of processing the component reflects. Among the proposed functional interpretations of the P600 are:

1. It is a general-purpose (non-linguistic) process such as the P3 elicited whenever enough information, of any type, has accumulated so as to require an updating of working memory (e.g. Coulson, King, & Kutas, 1998; Gunter, Stowe, & Mulder, 1997);
2. It is a reflection of specifically grammatical processing, related to (re)analysis whenever the parser fails to find a meaningful parse (Friederici & Mecklinger, 1996; Hagoort et al., 1993; Osterhout, 1994).
3. It is a re-analysis involving semantic processes (Münte, Matzke, & Johannes, 1997).

In some sense, it does not matter because in most of the linguistic settings, the response is clearly driven, in large part, by grammatical processing. As long as conditions (attention, meaning) are held constant and only syntactic processing is manipulated, a syntactic violation can be counted on to elicit some P600 activity, whose presence and timing can therefore be used to investigate various theories of parsing.

Most importantly, the P600 is not just a syntactic violation detector; it appears to be elicited at points of syntactic ambiguity (Brown, Hagoort, & Kutas, 2000; Hagoort & Brown, 1994). These are points in which the sentence can be interpreted in different ways, as at the word "coyote" in "The aardvark saw the ant and the coyote spotted the snake behind the rock"; here "coyote" could be what the aardvark saw or "coyote" could be who was doing the spotting of the snake. The fact that there are these two possible readings of the same set of words suggests different ways of structuring the words into sentence constituents. One interprets "the coyote" as a conjoint noun phrase, and the other interprets it as the beginning of a new sentence. The resolution of ambiguity in the example is at the verb "spotted", and is reflected in P600 activity. As can be seen in Figure 7.7 (data from Brown, Hagoort, & Kutas, (2000), an ambiguous reading (without a comma) reveals a P600, in contrast to an unambiguous reading (with comma).

For the moment we do not know exactly what processes are reflected in the P600 at the point of disambiguation. One idea, proposed by Brown, Hagoort, & Kutas, (2000), is that the parser uses one reading as default and has to change the interpretation at the moment the critical verb signals that only the second reading is possible. In the parsing literature it has been suggested that the conjoined noun phrase reading is a default (preferred) reading, for two reasons: (a) the syntactic structure is assumed to be less complex than for sentence conjunctions, and (b) the parser prefers less complex readings. Thus, the P600 effect might reflect the process of shifting from the default to an alternative reading, among other possibilities.

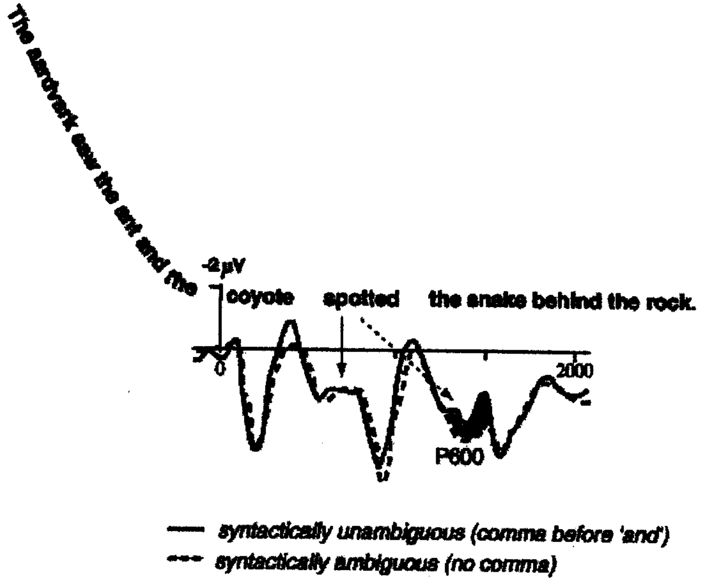


FIG. 7.7. Grand average ERPs to three words within syntactically ambiguous (dashed line) versus syntactically unambiguous (solid line) sentences: the syntactically ambiguous word, the disambiguating word, and the word following. Note the greater P600 or SPS to the disambiguating word ("spotted") relative to the same word, when a comma before "and" prevented an ambiguity. After Brown, Hagoort, and Kutas, (2000), with permission.

One of the stronger arguments in favor of the hypothesis that the P600 reflects some aspect of syntactic processing is the finding that it is elicited by violations of number agreement even in syntactic prose (i.e., semantically anomalous sentences) presented visually, one word at a time with punctuation as needed. As can be seen in Figure 7. 8 (top), a P600 ~~is elicited by the verb in "Two mellow graves~~ freely sinks by the litany" when it is marked singular with an "s" relative to when it is without the "s." Clearly, a sentence need not make sense to elicit some P600 activity. Thus, it would seem there is a purely syntactic representation of a sentence that can be violated. However, some data by Münte, Matzke, and Johannes (1997) suggest that a crucial element in the picture may be the possibility that a sentence might make sense (even if it does not). Take, for example, syntactic prose wherein real words are replaced by pseudowords (e.g., "Twe mullow grives freoly senks by the litune."). For these types of sentences, the ERP to the verb number violation does not elicit a P600 (see Fig. 7.8, bottom).

The lack of the P600 effect, however, was not because the brain is unaware that something is potentially amiss, because the violation is associated with a frontal negativity (not shown in the figure). The presence of the P600 in strings of words and its absence in strings of pseudowords suggest that the P600 may not be wholly independent of semantic processing.

But in the context of a meaningful sentence presented one word at a time visually or as natural speech, a syntactic violation or ambiguity resolution will elicit a P600. Thus, its presence or absence, amplitude, and/or latency can be used to test alternative accounts of how a sentence is parsed, what the preferred parse is, and the type of information that can override the preferred parse. Evidence, not detailed here, indicates that, at least sometimes, semantic and discourse information can influence the initial syntactic ambiguity of a sentence. For example, there would be no P600 to "spotted" in "The radio played the music and the coyote spotted the snake behind the rock," even though it includes a syntactic ambiguity, because radios do not "play coyote." So at times, semantic information can override the syntactic parse (see, e.g., Brown, Van Berkum, & Hagoort, 2000).

Sentence Processing and Working Memory: The Ultraslow Potentials

The temporal resolution of the ERP is such that it can be used to look at not only the very fast stop-consonant transitions such as those that differentiate a "g"

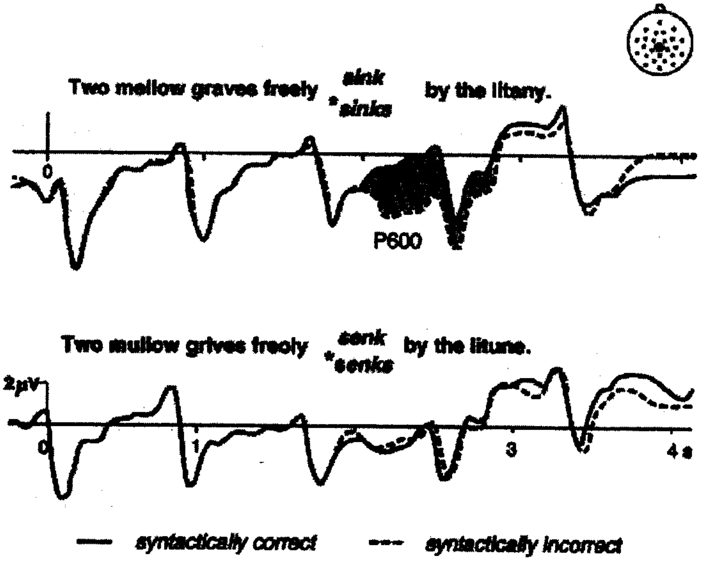


FIG. 7.8. Grand average ERPs elicited by morphosyntactic (subject–verb–number agreement) violations in meaningless sentences (prose). The solid lines show ERPs to syntactically correct sentences, and the dashed lines to incorrect sentences, wherein the verbs do not agree in number with their subject. At the top panel, the sentences are so-called syntactic prose. A syntactic violation in this case elicits a P600 effect (shaded area). In contrast, in the bottom panel, syntactic prose made of pseudowords is shown. Syntactic violations in pseudoword prose do *not* elicit a P600 effect. After Münte, Matzke, and Johannes (1997), with permission.

from a "d" but also the relatively slower processes that are needed to determine who did what to whom within a sentence or even discourse. By recording over an entire clause, we find a variety of very slow potentials (low frequency) on which the specific, transient evoked responses to the individual words are superimposed. The nature of the slow potential and the factors that seem to affect its behavior vary across the head (King & Kutas, 1995b). For visual stimuli there is a long-standing negativity over the visual areas at the back of the head. For auditory materials there is a long-standing negativity over the auditory areas located more centrally. For both written and spoken sentences, there is an ultraslow positivity over the frontal regions of the head (Müller, King, & Kutas, 1997). This ultraslow positivity has been hypothesized to reflect the linking of linguistic information and world knowledge in working memory during discourse processing (for reviews of discourse processing see Clark, 1994; Ericsson & Kintsch, 1995; Kintsch, 1994).

The interaction of linguistic processes and working memory can be seen in the comparison of simple and complex sentences. Sentences within sentences, that is, sentences with relative clauses, are typically more difficult to comprehend than those without embeddings because they are assumed to be more demanding on working memory. And even for relative clauses a distinction can be made in terms of complexity. In object-relative clauses as "The aardvark that the cop really scared ran into the bushes," several words pass before the reader/listener knows what grammatical or thematic role "aardvark" plays in the sentence. That is, several words must be read/heard before one can know what, if anything, the "aardvark" did or what, if anything, was done to the "aardvark" and if so by whom. This means the word "aardvark" has to stay in working memory for quite some time. This is not the case in subject-relative clauses, such as "The aardvark that really scared the cop ran into the bushes." Here, the same word "aardvark" is the subject of the main clause as well as of the relative clause.

As depicted in Figure 7.9, the ERP waveforms spanning entire clauses in these two sentence types show a divergence as soon as there is a difference in working memory load, with greater negativity observed for the more demanding sentence type. This difference is most pronounced over frontal sites of the left hemisphere. This general pattern holds whether the sentences are read one word at a time or naturally spoken (King & Kutas, 1995b; Müller et al., 1997).

At the level of the ERP to individual words, greater working memory load seems to be associated with negativity over the frontal regions of the left side of the head. In the example just given, the ERP to the main clause verb ("ran") would show relatively greater negativity between 200 and 800 msec after onset of the individual words when the "aardvark" did the running and the "cop" did the scaring than when the "aardvark" did both; this is the so-called left anterior negativity or LAN.

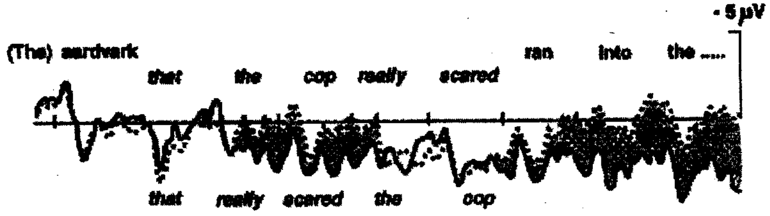


FIG. 7.9. Comparison of the grand-average cross-sentence ERPs elicited by subject relative (solid line) and object relative (dotted line) sentences recorded over a left frontal location. Words were visually presented one at a time every 500 ms for 200 ms each. The shading represents areas of where object relative sentences are reliably more negative than subject relative sentences (after King & Kutas, 1995b).

We observed a similar pattern of ERP effects to sentences designed to investigate how real-world knowledge and linguistic knowledge interact during sentence processing (Münte, Schiltz, & Kutas, 1998). Specifically, we examined how people's conceptions of time as flowing linearly influences their processing such that they might find it easier to understand (read) sentences that describe events in their natural order than sentences that describe events counter to their actual order of occurrence (i.e., a later event before an earlier event). We pursued this simply by changing the first words of sentences, all of which had two clauses. The sentences began either with the word "Before" or the word "After" as in "Before/After the scientist finished her lecture, the aardvark chewed the pointer." Linguistic and experience-based knowledge tells us how temporal conjunctions like "before" and "after" are normally used. Both of these temporal terms signal that part of the process of forming a discourse representation of this sentence will involve determining the temporal order of events in a discourse. "After" nearly always signals that events will be expressed in their natural order (consistent with real-world knowledge). "Before" nearly always signals that events will be expressed counter to their natural order. If real-world knowledge had no effect on sentence processing, then the brain's processing of the two sentence types should not differ. However, if world knowledge does affect language processing, then the two sentence types are likely to make different demands on working memory, with "before" sentences being more demanding.

As we show in Figure 7.10, world knowledge and sentence processing interact, at least in those individuals with high verbal working memory spans. (See top panel of the figure.) Within 300 msec of the onset of the first word of the sentence, the ERPs diverge and the difference only gets larger as the sentence proceeds. The nature of the difference is similar to that seen for sentences with embeddings. For individuals with low verbal working memory span, the effect is not present (as the bottom panel in Fig. 7.10 reveals). Their ERPs suggest that they find both sentence types quite demanding. Thus, we think the observed negativity reflects the added load on working memory processes, in this case for the building of a message or discourse representation, affected by both world knowledge and linguistic information (Goldman-Rakic, 1996; Just, Carpenter, Keller, Eddy, & Thulborn, 1996; Owen, 1997; Petrides, 1996; Stromswold, Caplan, Alpert, & Rauch, 1996).

In summary, ERPs provide insights into how world knowledge and linguistic knowledge meet in working memory. But most importantly, these data reveal when the different information sources meet, namely, quite early. A relatively high-level process at the discourse level influences how a word and then a sentence is processed by the brain, almost from the outset. These data effectively rule out any strictly serial model of language comprehension wherein the influence of a discourse-level representation would hardly be expected to manifest itself at the first word, whether written or spoken, much less only 300 msec after its appearance.

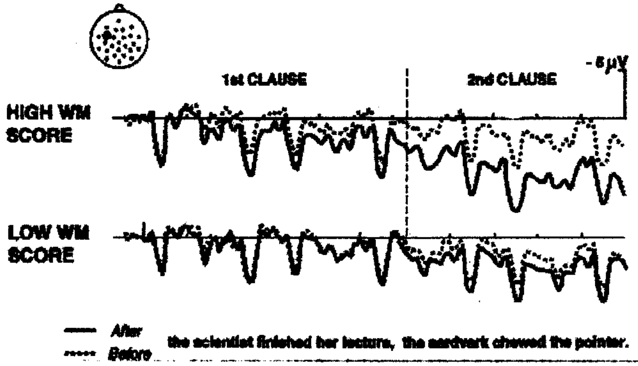


FIG. 7.10. Over-sentence ERPs from the left frontal recording site elicited by visually presented sentences that are equivalent in all respects except their initial word, either 'after' (solid lines) or 'before' (dotted lines). The top trace represents the responses of individuals with high working memory score (based on Daneman & Carpenter, 1980); while the bottom trace comes from individuals with low working memory scores. Individuals with higher working memory span show a more pronounced difference between 'before' and 'after' sentences than those with lower working memory span. These differences are seen within 300 ms of the response to the initial word (after Münte, Schiltz, & Kutas, 1998). Verbal working memory span is an estimate of an individual's temporary buffer for holding and processing of verbal information, presumably used during sentence processing. Loosely, it can be considered the number of language-like items that an individual can maintain for a few seconds without rehearsal.

Next stop on this journey through the brain/mind: the language production system.

FROM MIND TO MOUTH: LANGUAGE PRODUCTION

In our daily lives; we continually express thoughts and ideas in words. We talk about the present, the past, the future. We talk about what if, and about things that do not exist or never happened or never will. However, unless we encounter someone who stutters, has an accent, is too young to talk, is too demented to talk clearly, talks with difficulty due to a stroke, or does not want to talk, we take the ability to talk for granted. We do not think about how some abstract idea in the mind becomes a linguistic utterance that someone else must decipher.

Some psycholinguists, however, are very much concerned with how a concept in the mind comes to be a meaningful utterance. Broadly speaking, theories of language production agree that going from an idea to an utterance involves knowledge (at the least) at the level of (a) meaning, (b) syntax, and (c) phonological form (Bock, 1982, 1995; Dell, 1986, 1988; Garrett, 1975, 1988; Kempen & Huijbers, 1983; Levelt, 1989; Levelt, Roelofs, & Meyer, 1999). Research on patients with brain damage supports the assertion that there is a distinction between the semantic and syntactic levels (Rapp & Caramazza, 1995). Speech-errors (Dell, 1986, 1990, Dell & Reich, 1981;) and reaction-time data (Levelt, et al.,1991a, 1991b; Schriefers, Meyer, & Levelt, 1990) both support a distinction between semantic and phonological knowledge, as do findings on the tip-of-the-tongue phenomenon (Brown, 1991).

There is little agreement, however, on the time course or independence of the different processes that operate on these information types during natural speech production (e.g., Levelt et al., 1991a, 1991b, 1999; O'Seaghdha & Marin, 1997, for reviews). Some theories favor a serial view wherein conceptual/semantic information first activates syntactic information that in turn activates phonological encoding (Levelt et al., 1991a, 1991 Roelofs, 1992b; Schriefers et al., 1990). Others espouse a more interactive model of speech production with both top-down processing and bottom-up information flow (Dell & O'Seaghdha, 1991, 1992). Both positions are supported by empirical data. For instance, picture-word interference data show early semantic and late phonological activation of a picture's name during naming (Schriefers et al., 1990). However, the very existence of some types of errors (e.g., mixed errors—saying "rat" instead of the intended "cat" when viewing a picture of a cat) has been taken to suggest that semantic (animals) and phonological (rhyming) activation not only take place in parallel but can influence each other during speech production (Dell, 1990; but see also Levelt et al., 1999, for a different view).

This serial versus interactive activation debate hinges on issues of relative timing and thus would seem quite amenable to ERP research. But the act of speaking generates many electrical artifacts (muscle activity, tongue potentials) that can swamp the recorded brain activity (Brooker & Donald, 1980; Wohlert, 1993). Recently, however, Van Turennout, Hagoort, and Brown (1997, 1998, 1999) developed a method for examining preparation for speech production using the lateralized readiness potential (LRP). The LRP circumvents this problem of speech-related artifacts by focusing on preparation to speak rather than the speaking per se.

The LRP is derived from and related to the well-understood readiness potential (RP). The RP develops about a second or so before a voluntary hand movement as a negative-going potential, and is most prominent over central sites (Kornhuber & Deecke, 1965). Approximately half a second before the actual movement, the RP becomes lateralized, with larger amplitudes over the hemisphere contralateral to the moving hand (e.g., Kutas & Donchin, 1974). The LRP is derived from the RP, but is time-locked to the stimulus to which a response is given. By averaging the activity for responses made with the left and right hand (given contralateral vs. ipsilateral recordings), lateralized activity that is not related to response preparation cancels out. What remains is the lateralized part of the readiness potential; this LRP reflects the average amount of lateralization specifically related to the motor preparation of the responding hands. The LRP allows researchers to see motor-related brain activity prior to an overt response, even when the response is never realized (Miller, Riehle, & Requin 1992; Mulder, Wijers, Brookhuis, Smid, & Mulder, 1994; Osman, Bashore, Coles, Donchin, & Meyer, 1992). In essence, scientists can peer into the mind/brain and determine when it begins to prepare to respond and which type of response is going to be carried out (e.g., pressing a response button with the left or the right index finger [go response], or not responding at all [nogo response]). These features make the LRP an especially apt brain measure with which to study the time course of the encoding of various levels of information during speech production.

Sometimes Meaning Beats Phonology by a 120 msec: The LRP

Using the LRP, Van Turennout et al. ~~(1997) showed that semantic encoding pre~~cedes phonological encoding during picture naming. In one experiment, Dutch participants were asked to name pictures of animals and objects. On half of the trials, 150 msec after the appearance of the picture a frame appeared around it, cuing the participants to postpone their naming response and to perform a binary decision, known as a go/nogo task. The instruction was, for example, to press the left button if the picture was of an animal and the right button if it was of an inanimate object. However, the button response was to be executed only if the name of the pictured item ended with an "r," and was to be withheld if the picture name ended with an "s." (For an illustration of the design in English, see Fig. 7.11.)

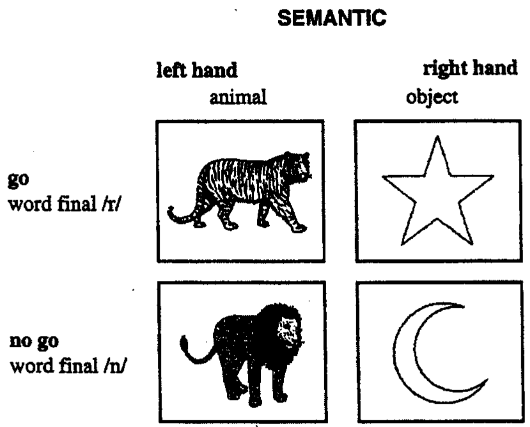


FIG. 7.11. An illustration of the design used in the first experiment of Van Turennout et al. (1997). The response hand was contingent on semantic information. The go–nogo response was contingent on phonological information. In the second experiment, the pictures were the same but the response contingencies were reversed: The response hand was contingent on phonological information. The go–nogo response was contingent on semantic information (after Van Turennout, Hagoort, & Brown, 1997).

The logic of the paradigm is as follows: It is assumed that people prepare to respond as soon as they have some information about what hand they are going to use. If semantic encoding precedes phonological encoding (as is assumed in serial models of speech production), and the responding hand is contingent on semantic information, then an LRP indicating preparation should develop for both go and nogo trials alike. Then, as soon as the phonological information is encoded indicating that no response is to be made, the LRP for go and nogo trials should diverge from each other, and the LRP for nogo trials should drop back to baseline. This was exactly the pattern of data Van Turennout et al. observed, as shown in the top panel of Figure 7.12.

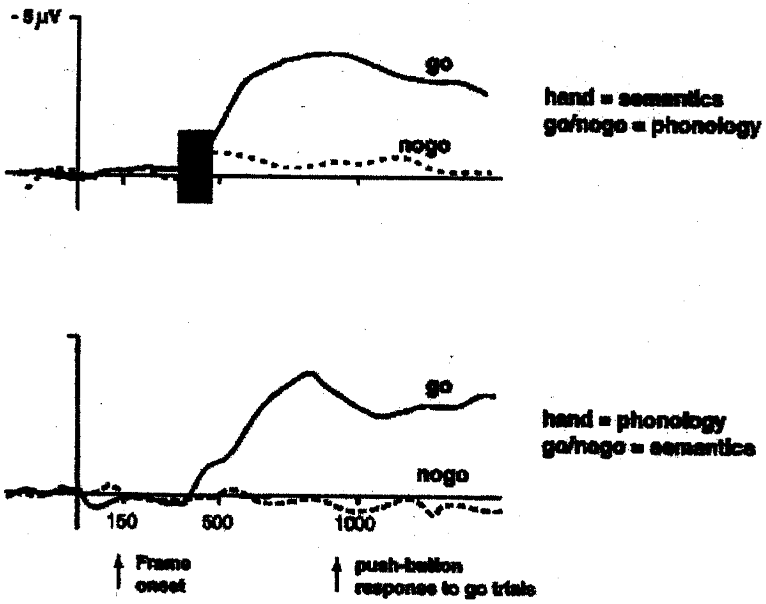


FIG. 7.12. Grand average lateralized readiness potential (LRP) on go (solid lines) and nogo trials (dashed lines) in a dual task that involves semantic and phonological decisions on picture names. The LRP is time-locked to picture onset. The top panel shows LRPs that were recorded when the outcome of the semantic decision determined the response hand, and the outcome of the phonological decision determined whether a response was required (go) or not (nogo). The shaded area indicates the interval during which the nogo LRP is reliably different from the baseline, and equivalent in amplitude to the go LRP. In the bottom panel are shown LRPs that were recorded when the response contingencies were reversed (phonological information determined the responding hand, and semantic decision whether or not a response was required). No reliable nogo LRP developed in this task (after Van Turennout, Hagoort, & Brown, 1997).

Van Turennout et al. also carried out a second experiment wherein the task instructions were reversed: The responding hand was contingent on the outcome of the phonological decision, and the decision about whether or not to respond was based on the semantic information. According to a serial model, no LRP should develop on nogo trials in this control experiment. This would be expected because the semantic information, which indicates that no response is to be given, would be available earlier than the phonological information, which would determine which response is to be given, thereby forestalling any preparation. As depicted in the bottom panel of Fig. 7. 12, Van Turennout et al. found no LRP on nogo trials. The authors thus concluded that semantic encoding precedes phonological encoding, in support of more serial-like models of speech production (e.g., Levelt et al., 1991a, 1991b, 1999; see also Van Turennout et al., 1998, 1999; Schmitt, Münte, & Kutas, 2000). These results demonstrate the sensitivity of the LRP as a tool for tapping into the time course of information access during (tacit) picture naming.

A Neural Stop: The N200

The ERPs associated with a go–nogo paradigm also offer another means of monitoring the time course of semantic, syntactic, and phonological processes during speech production. When an individual is asked to respond to one class of stimuli (go trials) and not to respond to another class (nogo trials), the ERPs to nogo (relative to go) trials are characterized by a large negativity (N200), especially over frontal sites (Gemba & Sasaki, 1989; Pfefferbaum, Ford, Weller, & Kopell, 1985; Sasaki, Gemba, Nambu, & Matsuzaki, 1993; Simson, Vaughan, & Ritter, 1977). While the functional significance of N200 is not yet clear (Eimer, 1993; Näätänen, 1982, 1992; Pfefferbaum et al., 1985), there is a consensus that it is elicited when a potential response is withheld. The N200 amplitude, therefore, is seen as a function of neuronal activity required for "response inhibition" (Jodo & Kayama, 1992; Sasaki & Gemba, 1993). This assumption is supported by studies that examined surface and depth (2–3 mm) recordings from the prefrontal cortex of monkeys (Sasaki, Gemba, & Tsujimoto, 1989), as they performed a go–nogo task on color discrimination. (That is, they pushed a button if a red light went on, and did not respond if a green light went on.) Nogo responses were associated with a cortical N200. Moreover, when this cortical area was stimulated electrically during a go trial at the time when the N200 would have been elicited, the go response was suppressed (see also Sasaki & Gemba, 1993, for a comparison of human and monkey data).

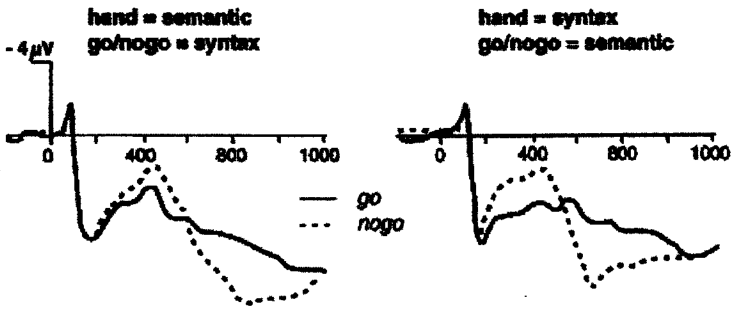
By defining the information on which the go–nogo decision is based, the peak latency of the N200 effect can be used to determine *when* the specific information is encoded, as shown by Thorpe, Fize, and Marlot (1996) for picture processing. Furthermore, by varying the information on which the go–nogo decision is based, this characteristic of the N200 can be used to delineate the temporal course of the availability of different information types during speech production. An early N200 means that the information that blocked the response on nogo trials was available early and vice versa.

Under Some Conditions Semantics Outperforms Syntax by 93 msec

Recently, we used the N200 to a nogo paradigm to investigate the availability of semantic and syntactic information during speech production (Schmitt, Schiltz, Zaake, Kutas, & Münte 2001). German-speaking participants were initially trained in the naming of simple line drawings of animals and objects. The training guaranteed that the participants actually knew and therefore would use the intended name of the pictures later in the main experiment. Afterwards, they saw the pictures again, and they either made a semantic decision (e.g., animal vs. object) or a syntactic judgment (e.g., whether the item's name has masculine or feminine gender).On different trials, the responding hand was contingent on semantic information and the go–nogo judgment was contingent on the syntactic information or vice versa. For example, volunteers might be given the following instructions: "Press left if the drawing is of an animal and press right if it is an object, but in both cases press only if the name has masculine gender" in one condition or "Press left if the name has masculine gender and press right if it has feminine gender, but in both cases press only if it is the name of an animal" in another condition. If semantic encoding takes precedence over syntactic encoding, then the information to stop should be available earlier when it is linked to semantic than to syntactic decisions. The ERPs of interest time-locked to the onset of the picture are shown in Fig. 7.13.

At the top left column are shown the ERPs elicited by the go–nogo trials when the responding hand (left versus right) was contingent on syntax and the semantics determined whether or not any response was executed. At the top of the right column are shown the ERPs when the response contingencies were reversed: The responding hand was contingent on semantics, the go–nogo response was based on syntax. In both cases, nogo trials elicited a large N200, albeit at different latencies. At the bottom panel, the N200 effect (the difference derived by subtracting go from nogo ERPs) in these two cases is compared directly. This comparison reveals that the N200 occurs much earlier (~90 msec) when the decision not to respond is governed by semantic rather than by syntactic information. This pattern of data supports serial models of speech production that assume initial semantic encoding followed by syntactic encoding (Bock & Levelt, 1994; Levelt et al., 1999).

However, it is also possible that, in this case, the semantic decision was simply easier and therefore occurred faster than the syntactic one, and it was this differential in decision difficulty that was reflected in the timing of the N200 effects. Naturally, we need to rule out this possibility in order to make sure that



Response inhibition (difference nogo - go)

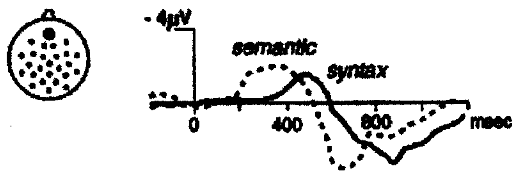


FIG. 7.13. Grand average ERPs on go and nogo trials in a dual task that involves semantic (animateness) and syntactic (syntactic gender in German) decisions on picture names. The ERPs are time locked to picture onset. At the top left figure are ERPs elicited in a condition, where the response hand was contingent on semantic information and the go–nogo decision was contingent on syntactic information. At the top right are ERPs where the response contingencies were reversed. Both conditions were associated with a frontal negativity (N200) that was more negative for nogo than for go trials. At the bottom, the difference waveforms (nogo minus go, interpreted as response inhibition) for the two conditions are shown superimposed. The solid line represents response inhibition when syntactic information determines the withholding of a response. The dashed line shows response inhibition when the semantic information determines the withholding of the response. The peak latencies for semantic response inhibition (i.e., N200 effect) are about 90 msec earlier than for syntactic response inhibition (Schmitt, Schiltz, Zaake, Münte, & Kutas, 2001).

the observed difference in the latencies of the N200 effects indeed tells us something about the timing of information access during speech processing and not just something about general decision making. Schmitt, Schiltz, Zaake, Kutas, and Münte (2001) ruled out this possibility in a follow-up study by showing that the N200 occurs much earlier (~80 msec) when the decision not to respond is governed by semantic rather than syntactic information, even when these two decisions were equated in difficulty when performed in isolation.

The N200 paradigm also has been successfully applied to a within-subject comparison of tacit picture naming and spoken word comprehension (Rodriguez-Fornells, Schmitt, Münte, & Kutas, 2000). Participants either saw pictures or heard the names of the pictured items. In both conditions on each trial they performed a dual choice go/nogo task that was based on semantic information (animal versus object) and on phonological information (picture's name begins with a vowel or a consonant sound). For tacit picture naming, the results replicated the study described earlier showing that the N200 effect based on semantics preceded that based on phonological information (in this case by ~190 msec); however, for spoken word comprehension the latencies of the N200 effects showed a reversed pattern. The N200 effect based on phonology preceded that based on semantic information (by ~100 msec), indicating that during comprehension phonological encoding comes first, as would be expected by speech comprehension models. Thus although comprehension and production both seem to access phonological and semantic information in a serial manner, the seriality appears to be more salient during production than comprehension.

In any case, the N200 component of the ERP is a very powerful tool for investigating temporal processes. The N200 reveals response-planning processes before response preparation (LRP), again even if no response is executed. Unlike the relatively small LRP elicited by nogo events, the N200 is quite robust. It may serve psycholinguists well as a tool for discerning fine–grained differences in rapidly occurring and closely related processes, such as those that characterize much of language production.

WHAT THE SYNCHRONOUS CACOPHONY OF NEOCORTICAL CELLS HAS TOLD US SO FAR

This overview of ERP findings of language processing shows that the method is an especially powerful tool for tapping the time course of language comprehension and production, including lexical/semantic, syntactic, and discourse-level processes.

The data obtained thus far suggest that there is a significant amount of temporal overlap and interaction not only among various linguistic representations but also between these and nonlinguistic knowledge representations during language comprehension. On the other hand, the data suggest that there is relatively more seriality, or at least a cascade of processes, during language production. By looking at various ERPs, (a) we can begin to catalog which sentence types are likely to be easier to comprehend, (b) we can point to the locations where the problems in comprehension might arise, and (c) we can establish what types of information might help reduce ambiguities or points of difficulty.

ERPs, such as the LRP or the N200, allow a view of the mind/brain as it plans to speak which is more direct than any other existing methodology. In fact, ERPs are more informative than simply asking a person what is going on in his or her head during language! Electrophysiological studies such as these thus afford researchers a means of combining information about the mind, the brain, and language in a natural way, thereby revealing the nature of the links between language and other cognitive domains, and between language and other cognitive functions.

We may need to leave it to future researchers to make sense of what various converging measures say about how human language works, but thank nature for the fact that it does so relatively effortlessly and that we can talk about "aardvarks" whenever the fancy to do so strikes us.

ACKNOWLEDGMENTS

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