Electrifying results

ERP data and cognitive linguistics

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1. Introduction

Have you ever heard anyone say that people typically use only 10% of their brains? I have. Interestingly, I've never heard anyone suggest that we typically only use 10% of our stomach, 10% of our kidneys, or 10% of our heart. Yet, like the stomach, the kidneys, and the heart, the brain is an organ made up of cells that undergo continuous metabolic activity. One thing that surely contributes to the "10%" myth is the way that neuroimaging data are shown pictorially. In arguing for the notion that people only use a small portion of their brains at a time, a friend of mine cited "studies" by "scientists" that show that only small areas of the brain light up. In such studies, PET (positron emission tomography) or fMRI (functional magnetic resonance imaging) is used to monitor changes in metabolic activity, such as blood flow or oxygen consumption, in different brain regions as a function of doing various cognitive tasks. Inspection of the raw images suggests that most of the brain is, in fact, active at any given moment. Neuroscientists, however, are most interested in the differences in brain activity as a function of task (e.g. reading words as opposed to tapping one's fingers up and down). Consequently, the pictures show only those brain areas that are *more* active during the performance of one task than the other.

A more direct way of measuring brain activity is to record electrical activity in its cells, also called *neurons*. The primary mechanism of neural computation is the action potential, or spike. A spike is a sudden change in the cell's voltage due to an influx of sodium ions followed by an expulsion of potassium. When a neuron is stimulated, its firing rate (how often spikes occur) changes, usually by getting faster. However, neurons fire even when they are not being stimulated, something known as their baseline firing rate. The cells in the brain, then, are always active in the sense that spikes occur at a particular frequency, and the firing rate changes as a function of the cell's engagement in some brain activity. Moreover, besides spikes, neurons receive a constant barrage of chemical signals from one another that result in slow changes to their voltage known as post-synaptic potentials.

As noted above, the brain is an organ which, like the stomach, the kidneys, and the heart, is made up of cells. Unlike the stomach, the kidneys, and the heart, however, the activity of cells in the brain is intimately related to our ability to see, hear, feel, think, and use language. One way to study the relationship between electrical activity in the brain and language comprehension is to record event-related brain potentials (ERPs). Rather than placing electrodes directly into the brain, ERPs are recorded by applying electrodes to the scalp, usually by having volunteers wear a hat that looks something like a swimming cap with electrodes embedded in it. This non-invasive method can nonetheless provide us with a direct index of brain activity. ERPs represent electrical activity in the brain that is time-locked to the onset of a cognitive or motor event, and are known to be sensitive to many of the processing operations involved in the production and comprehension of language.

This chapter reviews methods and data in the domain of electrophysiology of language comprehension. We begin with a general introduction to the electroencephalogram (EEG) and event-related brain potentials (ERPs), and give an overview of language-sensitive ERP components. Section 4 reviews the way that ERPs have previously been used to address issues in cognitive linguistics, and Section 5 points to a number of ways that this technique could be further employed by cognitive linguists.

2. EEG and ERPs

Work on the cognitive neuroscience of language has attempted to monitor how the brain changes with manipulations of particular linguistic representations. The assumption is that different language sub-processes are subserved by different anatomical and physiological substrates that will generate distinct patterns of biological activity. These patterns can then be detected by methods sensitive to electromagnetic activity in the brain, such as the electroencephalograph, or EEG. An EEG is a non-invasive measure of physiological activity in the brain made by hooking up electrodes to the subject's scalp. These electrodes pick up electrical signals naturally produced by the brain and transmit them to bioamplifiers. Early versions of the EEG used a galvanometer (an instrument that detects the direction of small electrical currents) to move a pen on a rolling piece of paper. In more modern EEG systems, the bioamplifiers convert information about voltage changes on the scalp to a digital signal that can be stored on a computer.

The idea of using EEG to study the brain processes that support the complex activity of language comprehension is frequently met with a healthy dose of skepticism. After all, it does seem far-fetched to assume that electrodes sitting on the surface of the head could be used to discern activity in the participants' brains. Initially, it might seem a bit like trying to study how a car works by listening to it with a stethoscope. However, although a functioning engine produces sound, the sound is not an integral part of its function. In contrast, the electrical activity in the brain *is* an integral part of its function. Neurons in different parts of the brain communicate with one another via electrochemical signals, and the success or failure of any given cognitive activity can depend on whether a particular pattern of firing occurs in the brain.

2.1 EEG

Because the brain constantly generates electrical activity, electrodes placed on the scalp can be used to record the electrical activity of the cortex (the outer part of the brain, and the part thought to be most integrally involved in cognition). The EEG amplifies tiny electrical potentials and records them in patterns called brain waves. Brain waves vary according to a person's state, as patterns observed when a person is alert and mentally active differ from those observed when she is relaxed and calm, and those observed when she is sleeping. Like any wave – an ocean wave, a sound wave, or a light wave – a brainwave can be described by certain mathematical properties. For example, it has a crest (or positive peak) and a trough (or negative peak). At any given point in a wave, one can ask what its *amplitude*, or size, is (see Figure 1). Typically, when one refers to the amplitude of a wave, it's the size of the wave at the peak that's being described. The *wavelength* of a wave is the distance between a point on a wave and the corresponding point on the next wave in the wave train, such as between the crest of one wave and the crest of the next. Finally, the *frequency* of a wave describes how many waves (or cycles) are made per second. When describing brainwaves, most neuroscientists focus on the amplitude and the frequency, especially since frequency and wavelength are two different ways of describing the same thing (see Figure 1).

The pattern of electrical activity in the fully awake person is a mixture of brainwaves that occur at many different frequencies. However, the EEG is dominated by waves of relatively fast frequencies between 15 and 20 cycles per second (or Hertz), referred to as beta activity. If the subject relaxes and closes her eyes, a distinctive pattern known as the alpha rhythm appears. The alpha rhythm consists of brainwaves oscillating at a frequency

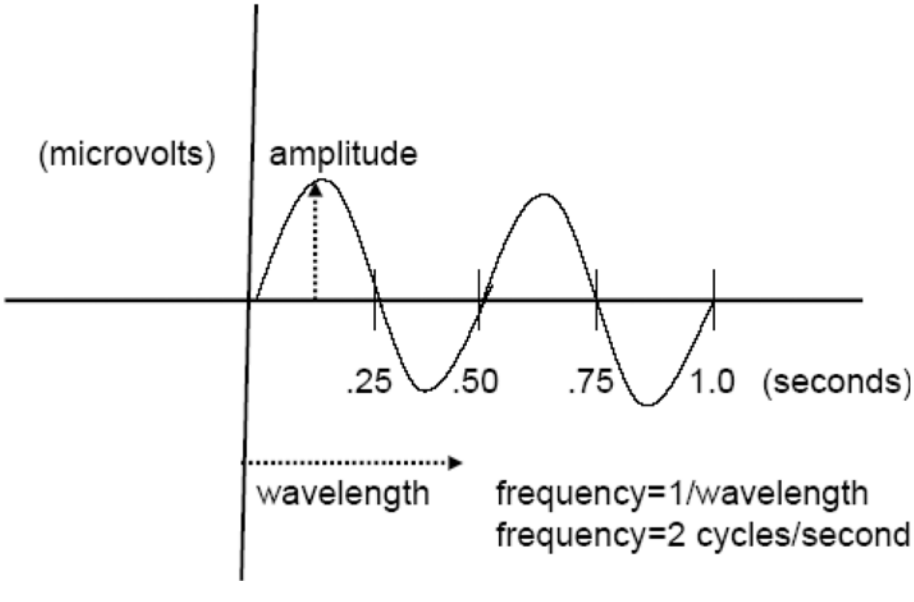

Figure 1. Two cycles of a waveform extended in time

that ranges from 9–12 Hertz. As the subject falls asleep, her brain waves will begin to include large-amplitude delta waves at a frequency of 1 Hertz.

Although the EEG provides overall information about a person's mental state, it can tell us little about the brain's response to specific stimuli. This is because there is so much background activity in the form of spontaneous brain waves it is difficult to identify which brain wave changes are related to the brain's processing of a specific stimulus and which are related to the many on-going neural processes occurring at any given time. In order to better isolate the information in the EEG that is associated with specific processing events, cognitive electrophysiologists average EEG that is time-locked to the onset of particular sorts of stimuli, or to the initiation of a motor response. The average EEG signal obtained in this way is known as the event-related potential, or ERP.

2.2 ERPs

ERPs are patterned voltage changes in the on-going EEG that are time-locked to classes of specific processing events. Most commonly these events involve the onset of stimuli, but they can also include the execution of a motor response (Hillyard & Kutas 1983; Rugg & Coles 1995). As noted above, we obtain ERPs by recording subjects' EEG and averaging the brain response to stimulus events. The effect of averaging different numbers of EEG trials can be seen in Figure 2. Each graph in Figure 2 shows the averaged EEG signal from an electrode at the top of the head that was recorded as a healthy adult listened to piano chords. Time is on the x-axis and voltage is on the y-axis, and thus the graphs show how voltage changes as a function of time. By convention, negative voltage is plotted upwards (not downwards).

The logic behind averaging, of course, is to extract from the EEG only that information which is time-locked to the processing of the event. The graph at the top of Figure 2 depicts the average signal from 3 trials. That is, for each time point measured (which in this case is every 4 milliseconds), the average voltage from the 3 trials has been plotted. This waveform has the oscillatory characteristics of the EEG and shows a substantial amount of activity during the time before the presentation of the chord (time 0 marks the onset of the stimulus). This is because the signal reflects not only the processing of the chord but brain activity related to other processes as well.

The different graphs in Figure 2 show how the signal changes when additional EEG trials are averaged into the waveform. The assumption is that brain activity related to the processing of the chord will be timelocked to its presentation, while brain activity related to other processes will not. The more trials in the averaged waveform, the more likely it is that the background activity will average to zero, so that the signal exclusively reflects the processing of the stimulus. Thus the graph at the bottom of Figure 2 shows virtually no activity before the presentation of the stimulus, followed by a series of peaks (the N1-P2 complex) that resemble those seen in other experiments in which people are presented with auditory stimuli.

Cognitive neuroscientists refer to the averaged signal as the event-related potential (ERP) because it represents electrical activity in the brain associated with the processing of a given class of events. In Figure 2, the "event" was the processing of a piano chord.

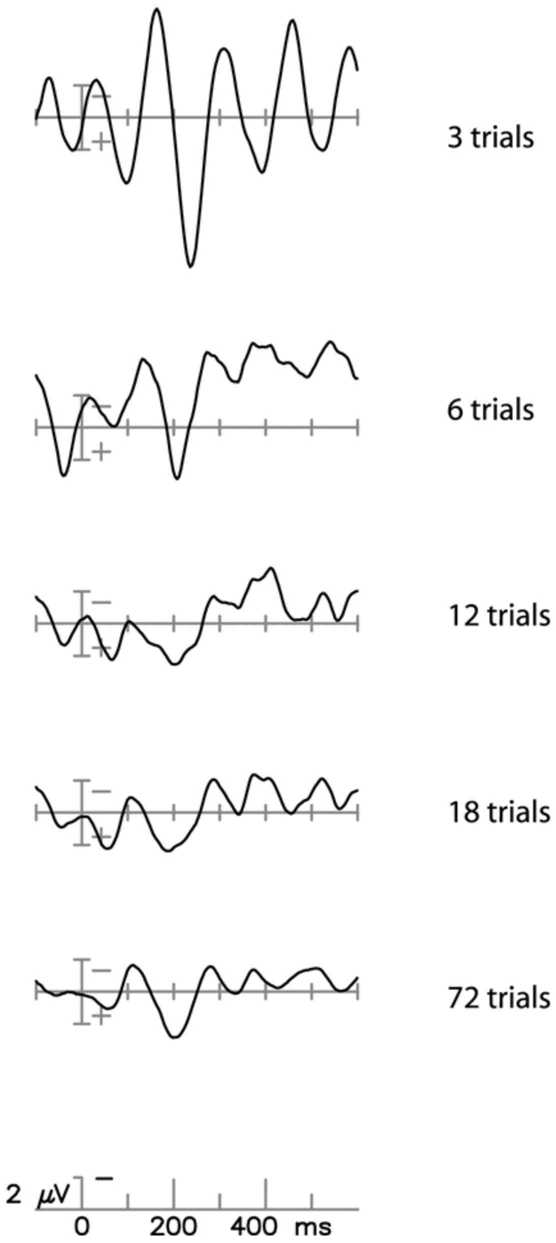

Figure 2. ERPs to piano chords from different numbers of trials (3, 6, 12, 18, and 72). Increasing the number of trials in the average decreases the amount of background activity and better represents activity related to processing the stimulus.

ERP language research involves interesting linguistic events such as the presentation of particular sorts of words. For example, in early work on language processing, Kutas and Hillyard (Kutas & Hillyard 1980) recorded ERPs to the last word of sentences that either ended congruously (as in (1)), or incongruously (as in (2)).

(1) I take my coffee with cream and sugar.
(2) I take my coffee with cream and dog.

Because the EEG associated with the presentation of a single event is relatively inscrutable, Kutas & Hillyard constructed 70 sentences, half of which ended congruously, half incongruously (Kutas & Hillyard 1980). By averaging the signal elicited by congruous and incongruous sentence completions, respectively, these investigators were able to reveal systematic differences in the brain's electrical response to these stimulus categories in a particular portion of the ERP that they referred to as the N400 component. Subsequent research has shown that N400 components are generated whenever stimulus events involve meaningful processing of the stimuli, and that its size is sensitive to fairly subtle differences in the processing difficulty of the words that elicit it. As such, many investigators have used the N400 component of the brain waves as a dependent variable in psycholinguistic experiments (see Kutas, Federmeier, Coulson, King, & Muente 2000 for review).

2.3 ERP components

While EEG measures spontaneous activity of the brain and is primarily characterized by rhythmic electrical activity, the ERP is a waveform containing a series of deflections that appear to the eye as positive and negative peaks. Such peaks are often referred to as components, and much of cognitive electrophysiology has been directed at establishing their functional significance. ERP components are characterized by their *polarity*, that is, whether they are positive- or negative- going, their *latency*, the time point where the component reaches its largest amplitude, and their *scalp distribution*, or the pattern of relative amplitudes the component has across all recording sites. The N400, for instance, is a negative-going wave that peaks approximately 400 ms after the onset of the stimulus, and has a centro-parietal distribution (evident over the back of the head) which is slightly larger over the right hemisphere.

The ERP approach seeks correlations between the dimensions of ERP components elicited by different stimuli and putatively relevant dimensions of the stimuli themselves. ERP components with latencies under 100 ms are highly sensitive to systematic variations in the physical parameters of the evoking stimulus. Because their amplitudes and latencies seem to be determined by factors outside the subject, they are referred to as *exogenous* components. In contrast, *endogenous* ERP components are less sensitive to physical aspects of the stimulus, reflecting instead the psychological state of the subject. Endogenous components are modulated by task demands and other manipulations that affect the subjects' expectancies, strategies, and mental set. Because they are thought to reflect cognitive rather than perceptual processing, most language researchers have restricted their attention to the endogenous ERP components elicited by linguistic stimuli.

The P300 component of the ERP is the prototypical example of an endogenous component because its amplitude is modulated by subjective aspects of experimental stimuli, such as their salience, their task relevance, and their probability. The first P300 reported in the literature was a positivity that peaked 300 ms after stimulus onset. However, cognitive neuroscientists have subsequently observed a whole family of positive-going components of varying latency, all of which are referred to by the P300 moniker. P300s are elicited by any stimulus that requires the participant to make a binary decision. The amplitude of this response is proportional to the rarity of the target stimulus, as well as how confident the participant is in her classification judgment. The latency of the P300 (i.e. the point in time at which it peaks) varies with the difficulty of the categorization task, and ranges from 300 to over 1000 ms after the onset of the stimulus (Donchin, Ritter, & McCallum 1978; Kutas, McCarthy, & Donchin 1977; Magliero 1984; McCarthy 1981; Ritter et al. 1983).

While not specifically sensitive to language, P300s will be elicited in any psycholinguistic paradigm that requires a binary decision. As long as the experimenter is aware of the conditions known to modulate the P300, this component can serve as a useful dependent measure of language-relevant decision-making. For example, participants might be presented with a sentence, and then asked to judge its grammaticality. The amplitude of the P300 in such a case varies with the participant's confidence in her decision, and its latency indexes when the decision is made. This sort of experimental paradigm could thus be used to test hypotheses about the existence of a precisely characterized continuum of grammaticality. However, because P300 amplitude is very sensitive to stimulus probability, the number of critical stimuli in each experimental condition must be held constant. Another thing to be aware of is the fact that task-induced P300s may overlap in time with more specifically language sensitive ERP effects such as the N400.

Figure 3 shows ERPs elicited by the last word of sentences that ended either congruously or incongruously. Each graph shows the ERPs recorded at a different electrode site, as indicated in the little head. As is typical for these sorts of figures, the graph at the top of the figure corresponds to the electrode closest to the front of the head (where the nose is), and the graph at the bottom corresponds to the electrode over the back of the head. The solid line represents the average signal timelocked to the presentation of the last word in each congruous sentence, while the dotted line is the ERP to incongruous sentence completions. Visually presented words typically elicit 3 components, the N1, the P2 and the N400. The N1 and the P2 are thought to reflect different aspects of the visual processing of the words, and consequently are the same size for the congruous and the incongruous stimuli. The N400 is larger for the incongruous stimuli, and this component is thought to reflect the processing of the meaning of the stimuli.

3. Language sensitive ERPs

Since the discovery of the N400, cognitive neuroscientists interested in language have frequently appealed to ERPs as a dependent measure in psycholinguistic experiments. As a result, a number of language-sensitive ERP components have been reported (see (Kutas et al. 2000; Kutas & Van Petten 1994) for review). Although most of this research has been

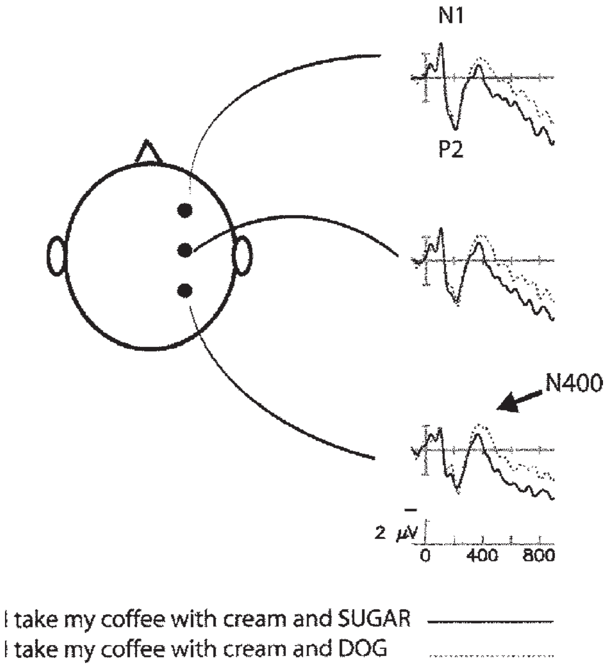

Figure 3. ERPs to the last word of congruous (solid) and incongruous (dotted) sentences

motivated by generative approaches to sentence processing, these finding may prove valuable to researchers interested in cognitive linguistics. Below we review ERP components known as the N400, the lexical processing negativity (LPN), the left anterior negativity (LAN), the P600, as well as slow cortical potentials, and briefly discuss the utility of each for studies of language comprehension.

3.1 N400

The N400 is a negative-going wave evident between 200 and 700 ms after the visual presentation of a word. Though this effect is observed all over the scalp, it is largest over centroparietal areas and is usually slightly larger on the right side of the head (Kutas, Van Petten, & Besson 1988). The N400 is elicited by words in all modalities, whether written, spoken, or signed (Holcomb & Neville 1990). Moreover, the size, or amplitude, of the N400 is affected in a way that is analogous in many respects to popular measures of priming in psycholinguistics, such as naming and lexical decision latencies.

For instance, in both word lists and in sentences, high frequency words elicit smaller N400s than low frequency words (Smith & Halgren 1989). The N400 also evidences semantic priming effects, in that the N400 to a word is smaller when it is preceded by a related word than when it is preceded by an unrelated word (Bentin 1987; Holcomb 1988). Third, the N400 is sensitive to repetition – smaller to subsequent occurrences of a word than to the first (Rugg 1985; C. Van Petten, Kutas, Kluender, Mitchiner, & McIsaac

1991). Further, while pseudowords (orthographically legal letter strings) elicit even larger N400s than do real words, orthographically illegal nonwords elicit no N400 at all (Kutas & Hillyard 1980).

In addition to its sensitivity to lexical factors, the N400 is sensitive to contextual factors related to meaning. For example, one of the best predictors of N400 amplitude for a word in a given sentence is that word's cloze probability (Kutas & Hillyard 1984). Cloze probability is the probability that a given word will be produced in a given context on a sentence completion task. The word "month" has a high cloze probability in "The bill was due at the end of the –," a low cloze probability in "The skater had trained for many years to achieve this –," and an intermediate cloze probability in "Because it was such an important exam, he studied for an entire –." N400 amplitudes are large for unexpected items, smaller for words of intermediate cloze probability, and are barely detectable for contextually congruous words with high cloze probabilities. In general, N400 amplitude varies inversely with the predictability of the target word in the preceding context.

Because initial reports of the N400 component involved the last word of a sentence, many people have the misconception that the N400 is an ERP component elicited by sentence final words. However, N400 is typically elicited by all words in a sentence. Interestingly, the size of the N400 declines across the course of a congruent sentence, starting large and becoming smaller with each additional open-class word. This effect has been interpreted as reflecting the buildup of contextual constraints as a sentence proceeds because it does not occur in grammatical but meaningless word strings (Van Petten & Kutas 1991). In general, the amplitude of the N400 can be used as an index of processing difficulty: the more demands a word poses on lexical integration processes, the larger the N400 component will be. This feature of the N400 makes it an excellent dependant measure in language comprehension experiments. As long as words in different conditions are controlled for length, frequency in the language, ordinal position in a sentence, and cloze probability, N400 amplitude can be used as a measure of processing effort. The N400 component is thus useful for testing hypotheses about the relative processing difficulty of minimal pairs of sentences.

Besides words, the N400 component is also elicited by pictorial stimuli. For example, line drawings of objects elicit a larger N400 when they are preceded by an unrelated word than by a related word (Praterelli 1994). Similarly, both line drawings and photographs of objects elicited a larger N400 when preceded by pictures of semantically unrelated than related objects (Holcomb & McPherson 1994; McPherson & Holcomb 1999). The N400 is larger for objects that occur in an incongruous scene (e.g. a desk in a river) than in a congruous one (e.g. a pot in a kitchen) (Ganis & Kutas 2003). Similarly, the N400 is larger for contextually inappropriate than appropriate objects in video clips of common activities, as in the contrast between a man shaving with a rolling pin versus a razor (Sitnikova, Kuperberg, & Holcomb 2003). Pictorial stimuli thus elicit the N400 component in a way that reflects the congruency of the pictured object with surrounding context, both linguistic and nonlinguistic.

3.2 LPN

The lexical processing negativity (LPN) is a brain potential to written words that is most evident over left anterior regions of the scalp. Its association with lexical processing derives from the fact that its latency is highly correlated with word frequency, peaking earlier for more frequent words (King & Kutas 1998). This component was originally thought to be an electrophysiological index of the brain's distinction between open-class content words and closed-class function words as the so-called N280 component was elicited by closed but not open class words (Neville, Mills, & Lawson 1992). However, subsequent testing indicated that word class effects are attributable to quantitative differences in word length and frequency (Osterhout, Bersick, & McKinnon 1997). That is, two words with the same frequency in the language elicit LPNs with the same latency even if one is an open-class word and the other a closed-class word (King & Kutas 1998). Because its latency is sensitive to word frequency, this component is useful as an indicator that the initial stages of lexical processing have been completed.

3.3 LAN

Researchers have also identified ERP components that seem to be sensitive to syntactic manipulations. The first is a negativity that occurs in approximately the same time window as the N400 (that is, 300–700 ms post-word onset) and is known as the LAN (left anterior negativity) because it is most evident over left frontal regions of the head. Kluender & Kutas described this component in a study of sentences containing long distance dependencies that required the maintenance of information in working memory during parsing (Kluender & Kutas 1993). Similarly, King & Kutas (King & Kutas 1995) described this component as being larger for words in object relative sentences like (3) that induce a greater working memory load than subject relative sentences like (4).

(3) The reporter who the senator attacked admitted the error.
(4) The reporter who attacked the senator admitted the error.

As an ERP component sensitive to working memory load, the LAN can be used to index differences in the processing difficulty of appropriately controlled stimuli.

3.4 P600

Another ERP component sensitive to syntactic and morphosyntactic processing is the P600. This slow positive shift has been elicited by violations of agreement, phrase structure, and subcategorization in English, German, and Dutch (Coulson, King, & Kutas 1998; Hagoort 1993; Mecklinger, Schriefers, Steinhauer, & Friederici 1995; Neville, Nicol, Barss, Forster, & Garrett 1991; Osterhout & Holcomb 1992). This component is typically described as beginning around 500 ms post-stimulus, and peaking at approximately 600 ms. Its scalp distribution tends to be posterior (larger over the back of the head), although anterior effects have also been reported (see Coulson et al. 1998 for review). Because the broad positivity is elicited by syntactic errors, it has been hypothesized to reflect a re-analysis of sentence structure triggered by such errors (Hahne & Friederici 1999).

However, Coulson and colleagues (Coulson et al. 1998) found that the amplitude of the P600 varied with the probability of ungrammatical trials within an experimental block. In one half of their study, 80% of the sentences were grammatical (the probable event), and only 20% ungrammatical (and improbable). In the other half of the study, 80% of the sentences were ungrammatical (and thus were the probable event), and only 20% grammatical (and thus improbable). The grammaticality effect (P600) was much smaller when ungrammatical sentences were probable than when they were improbable. In fact, the P600 to all improbable trials (collapsed across grammaticality) was very similar to the P600 to all ungrammatical trials (collapsed across probability).

Coulson and colleagues have argued that the P600 is not a syntax-specific component but rather a variant of a domain general component in the P300 family which has been hypothesized to reflect "context-updating," a process in which the subject recalibrates her expectations about the pattern of events in the environment (Donchin & Coles 1988). This interpretation is bolstered by recent evidence that P600 (but not N400) is elicited by semantic reversal anomalies such as "The cat that fled from the mice ran across the room," (Kolk, Chwilla, van Herten, & Oor 2003).

In any case, the fact that syntactic violations are associated with the late positive ERP known as the P600 provides a theory-neutral tool for testing when speakers find sentences to be ungrammatical, and potentially how manipulations of, for example, construal might have a graded effect on this electrophysiological index of ungrammaticality.

3.5 Slow cortical potentials

Besides phasic ERPs, temporally extended tasks such as reading or speech comprehension also elicit electrical changes with a slower time course. In order to examine slow brain potentials, it is necessary to average several seconds worth of data (viz. average EEG that begins at the onset of a particular class of language stimuli and ends several seconds later), apply a low-pass filter to the ERP data, and restrict analysis to activity less than 0.7 Herz. Kutas describes three slow brain potentials which have be elicited in experimental studies of written language comprehension (Kutas 1997). The first is a left lateralized negative shift evident at electrodes placed over occipital (visual) cortex, thought to reflect early visual processing. The second is the clause ending negativity (CEN), an asymmetric negativity larger over left hemisphere sites that may be associated with sentence wrap-up operations. The third is an ultra-slow (<0.2 Hertz) positivity over frontal sites that may be associated with discourse integration.

4. ERPs and cognitive linguistics

4.1 Frames

One important idea in cognitive linguistics is that words (and other sorts of linguistic structure) are not intrinsically meaningful, but are used by speakers to actively construct meaning. Lee (2002), for example, urges us to think of words as "tools that cause listeners to activate certain areas of their knowledge base, with different areas activated to different degrees in different contexts of use." Fillmore (Fillmore 1968) noted that understanding the meaning of many words requires an understanding of the concepts and conventions that surround their use. For example, "weekend" presumes an understanding of the structure of the week. Moreover, a true appreciation of the meaning of "weekend" involves cultural knowledge that many people in industrialized countries work Monday through Friday, but not on Saturday and Sunday.

In cognitive linguistics, frame semantics is a research program in which a word's semantic properties are described with respect to the way that they highlight aspects of an associated frame, or structured set of background assumptions. For example, "buy" and "sell" both evoke what might be dubbed the Commercial Transaction frame (Fillmore 1968). But "buy" highlights the buyer and the goods, while "sell" highlights the seller and the money. Langacker (Langacker 1987) argues that while "roe" and "caviar" refer to the same thing, their meanings differ because "roe" presumes a biological frame, while "caviar" presumes a culinary one. Conversely, Lakoff (Lakoff 1987)shows how many variants on the meaning of "mother," (as in "my birth mother" versus "my adopted mother") can arise because their meaning presumes different frames or idealized cognitive models of parenthood.

This tenet of cognitive linguistics thus suggests that background knowledge represented in frames figures prominently in the establishment of meaning, as language functions against this backdrop of conceptual structure. Although the psychological reality of frames has not been a big issue in language research, there is some ERP data consistent with the idea that background information represented in frames impacts language comprehension. In one such experiment, St. Georges, Mannes, & Hoffman (St. George, Mannes, & Hoffman 1994) recorded participants' ERPs as they read ambiguous paragraphs that either were or were not preceded by a disambiguating title. For example, people read paragraphs like the following (from (Bransford & Johnson 1972) "The procedure is actually quite simple. First you arrange items into groups. Of course one pile may be sufficient depending on how much there is to do. . .. After the procedure is complete one arranges the materials into different groups again. Then they can be put in their appropriate places. Eventually they will be used once more and the whole cycle will then have to be repeated. . .."

The title for this example is "Washing Clothes" and provides the subject with information about the appropriate frame to activate. Behavioral research by Bransford & Johnson showed that people both understood the paragraphs better and were better able to remember their contents when they were preceded by titles than when they were not. St. George and colleagues found that words in the untitled paragraphs elicited greater amplitude N400s than the same words in titled paragraphs. Although the local contextual clues provided by the paragraphs were identical in the titled and untitled conditions, ERPs revealed real-time processing differences in the lexical integration of words in the two conditions. These findings suggest that activating the frame facilitated the comprehension of these materials.

The study of joke comprehension also addresses the importance of frames for language comprehension, since many jokes are funny because they deceive the listener into using the wrong frame to help interpret the information presented in the first part of the joke. For example, consider the following joke, "I let my accountant do my taxes because it saves time: last spring it saved me ten years." Initially, the listener assumes a busy-professional frame is active; however, at the punch-line "saved me ten years" it becomes apparent that a crooked-businessman frame is more appropriate. Although lexical reinterpretation plays an important part in joke comprehension, to truly appreciate this joke it is necessary to recruit background knowledge about particular sorts of relationships that can obtain between business people and their accountants so that the initial busy professional interpretation can be mapped into the "crooked-businessman" frame. Coulson refers to the semantic and pragmatic reanalysis needed to understand examples like this one as frame-shifting (Coulson 2001).

Given the impact of frame-shifting on the interpretation of one-line jokes, one might expect the underlying processes to take time, and consequently be reflected in increased reading times in behavioral tests of processing difficulty such as self-paced reading. In this paradigm, the task is to read sentences one word at a time by pressing a button to advance to the next word. As each word appears, the preceding word disappears, so that the experimenter gets a record of how long the participant spent reading each word in the sentence. Coulson & Kutas (1998) used this method to compare reading times for sentences that ended as jokes with reading times for the same sentences with non-funny "straight" endings that were consistent with the contextually evoked frame. Two types of jokes were tested, high constraint jokes like (5) which elicited at least one response on a sentence completion task with a cloze probability of greater than 40%, and low constraint jokes like (6) which elicited responses with cloze probabilities of less than 40%. For both (5) and (6) the word in parentheses is the most popular response on the cloze task.

(5) I asked the woman at the party if she remembered me from last year and she said she never forgets a (face 81%).

(6) My husband took the money we were saving to buy a new car and blew it all at the (casino 18%).

To control for the fact that the joke endings are (by definition) unexpected, the straight controls were chosen so that they matched the joke endings for cloze probability, but were consistent with the frame evoked by the context. For example, the straight ending for (5) was name (the joke ending was *dress*); while the straight ending for (6) was tables (the joke ending was *movies*). The cloze probability of all four ending types (high and low constraint joke and straight endings) was equal, and ranged from 0%–5%. Coulson & Kutas (Coulson & Kutas 1998) found that readers spent longer on the joke than the straight endings, and that this difference in reading times was larger and more robust in the high constraint sentences. This finding suggests there was a processing cost associated with frame-shifting reflected in increased reading times for the joke endings, especially in high constraint sentences that allow readers to commit to a particular interpretation of the sentence.

In a very similar ERP study of the brain response to jokes, Coulson & Kutas (Coulson & Kutas 2001) found that ERPs to joke endings differed in several respects from those to the straight endings, depending on contextual constraint as well as participants' ability to get the jokes. In poor joke comprehenders, jokes elicited a negativity in the ERPs between 300 and 700 milliseconds after the onset of the sentence-final word. In good joke comprehenders, high but not low constraint joke endings elicited a larger N400 than the straight endings. Also, in this group, both sorts of jokes (high and low constraint) elicited a late positivity in the ERP (500–900 ms post-onset) as well as a slow sustained negativity over left frontal sites. Multiple ERP effects of frame-shifting suggest the processing difficulty associated with joke comprehension involves multiple neural generators operating with slightly different time-courses.

Taken together, these studies of frame-shifting in jokes are far more informative than either study alone. The self-paced reading time studies suggested that frame-shifting needed for joke comprehension exerts a processing cost that was especially evident in high constraint sentence contexts (Coulson & Kutas 1998). ERP results suggested the processing cost associated with frame-shifting is related to higher-level processing (Coulson & Kutas 2001). In the case of the high constraint jokes, the difficulty includes the lexical integration processes indexed by the N400, as well as the processes indexed by the late-developing ERP effects. In the case of the low constraint jokes, the difficulty was confined to the processes indexed by late-developing ERP effects. The added difference in lexical integration indexed by the N400 may explain why joke effects on reading times were more pronounced for high constraint sentences than for low. Because the late developing ERP effects were only evident for good joke comprehenders who successfully frame-shifted, they are more likely to be direct indices of the semantic and pragmatic reanalysis processes involved in joke comprehension.

As a general methodological point, the demonstration of individual differences in memory, vocabulary, language ability, or, in this case, on-line comprehension, can be extremely informative when they can be correlated with particular ERP effects. Coulson & Kutas (Coulson & Kutas 2001), for example, were able to determine that the N400 joke effect was not an index of successful frame-shifting as it was evident in ERPs collected from both good and poor joke comprehenders. In contrast, the late positivity present only in good comprehenders' ERPs was argued to be more closely related to the frame-shifting process important for understanding jokes. Researchers in experimental cognitive linguistics would do well to consider how individual differences in cognitive abilities affect various language comprehension phenomena and their manifestations in the ERP signal. Moreover, work on joke comprehension by Coulson & Kutas demonstrates how ERPs and reaction time data for the same stimuli can provide complementary information about the underlying cognitive processes.

4.2 Metaphor

In fact, ERPs can reveal reliable differences even when no reaction time differences are evident. This is important because reaction times are typically interpreted as reflecting processing difficulty, yet it is quite possible for two processes to take the same amount of time, but for one to recruit more neural processing resources. One issue in cognitive linguistics where this has been an important issue is the study of metaphor comprehension. Because classical accounts of metaphor comprehension (Grice 1975; Searle 1979) depict a two-stage model in which literal processing is followed by metaphorical processing, many empirical studies have compared reading times for literal and non-literal utterances and found that when the metaphorical meaning was contextually supported, reading times were roughly similar. However, as Gibbs notes, parity in reading times need not entail parity in the underlying comprehension processes (Gibbs 1994). It is possible, for example, that literal and metaphorical meaning might take the same amount of time to comprehend, but that the latter required more effort or processing resources. Alternately, comprehension processes for literal versus metaphorical utterances might take the same amount of time to complete, and yet involve quite different computations (Gibbs & Gerrig 1989).

Because they involve a direct and continuous measure of brain activity, ERPs can potentially distinguish between qualitatively different sorts of processing, even if their corresponding behavioral manifestations require the same amount of time. Taking advantage of the known relationship between N400 amplitude and processing difficulty, Pynte and colleagues contrasted ERPs to familiar and unfamiliar metaphors in relevant versus irrelevant contexts (Pynte et al. 1996). They found that regardless of the familiarity of the metaphors, N400 amplitude was a function of the relevance of the context. Moreover, by using ERPs, Pynte and colleagues employed a measure which is in principle capable of revealing the qualitative processing differences by the standard (Gricean) pragmatic model. In fact, they observed no evidence of a qualitative difference in brain activity associated with the comprehension of literal and metaphoric language.

Reports that literal and metaphorical language comprehension display a similar time course and recruit a similar set of neural generators are consistent with a number of modern models of metaphor comprehension (Coulson & Matlock 2001; Gibbs 1994; Giora 1997; Glucksberg 1998). Coulson's (Coulson 2001) model also makes predictions for comprehension difficulty, predicting a gradient of processing difficulty related to the extent to which comprehension requires the participant to align and integrate conceptual structure from different domains. This prediction was tested by Coulson & Van Petten (Coulson & Van Petten 2002) when they compared ERPs elicited by words in three different sentence contexts on a continuum from literal to figurative, as suggested by conceptual blending theory (Fauconnier & Turner 2002). For the literal end of the continuum, Coulson & Van Petten used sentences that promoted a literal reading of the last term, as in "He knows that whiskey is a strong INTOXICANT." At the metaphoric end of the continuum, they used sentences which promoted a metaphoric reading of the last term, as in "He knows that power is a strong INTOXICANT." Coulson & Van Petten also posited a literal mapping condition hypothesized to fall somewhere between the literal and the metaphoric uses, such as, "He has used cough syrup as an INTOXICANT."

Literal mapping stimuli employed fully literal uses of words in ways that were hypothesized to include some of the same conceptual operations as in metaphor comprehension. These sentences described cases where on object was substituted for another, one object was mistaken for one another, or one object was used to represent another – all contexts that require the comprehender to set up mappings between the two objects in question, and the domains in which they typically occur. In positing a continuum from literal to metaphorical based on the difficulty of the conceptual integration needed to comprehend the statement, Coulson & Van Petten (2002) predicted a graded difference in N400 amplitude for the three sorts of stimuli.

Data reported by Coulson & Van Petten were largely consistent with these predictions. In the early time window, 300–500 ms post-onset and before, ERPs in all three conditions were qualitatively similar, displaying similar waveshapes and scalp topography. This suggests that during the initial stages, processing was similar for all three sorts of contexts. Moreover, as predicted N400 amplitude differed as a function of metaphoricity, with literals eliciting the least N400, literal mappings the next-most, and metaphors eliciting the most N400, suggesting a concomitant gradient of processing difficulty. The graded N400 difference argues against the literal/figurative dichotomy inherent in the standard model, and is consistent with the suggestion that processing difficulty associated with figurative language is related to the complexity of mapping and conceptual integration.

4.3 Iconicity

One way that cognitive linguistics differs from more traditional approaches to language is the assumption that the relationship between linguistic forms and their meaning is often iconic. An iconic relationship between a symbol and its referent is one in which the symbol shares some structure with the thing that it represents. While linguists have traditionally assumed the relationship between words and their referents is arbitrary and established by convention, cognitive linguists posit a much higher degree of iconicity in language. It is assumed that the presence of iconic motivation for linguistic forms makes it easier to learn a language, and provides a basis for language change over time.

Langacker (Langacker 1997, 1999) argues that because all conceptualization unfolds dynamically in real time, the temporal dimension of language is a critical one that is bound to have linguistic ramifications. Langacker (Langacker 2003) notes that one of the most obvious of these is the iconic use of word order to suggest the sequence of events. For example, contrast (7) and (8).

(7) She got married and had a baby.

(8) She had a baby and got married.

Of course, Langacker does not suggest that linguistic constructions must be iconic in this way. Rather, he claims that because the function of linguistic constructions is to guide conceptualization, the dynamic nature of conceptualization imposes certain constraints on linguistic structure. For instance, Langacker (Langacker 2003) argues that (9a) is more natural than (9b), because in the former the meaning of "from" and "to" serve to reinforce the iconically cued pattern of mental scanning (knee → ankle), whereas they conflict with it in (9b).

(9) a. A scar extends from his knee to his ankle.
    b. A scar extends to his knee from his ankle.

While these claims are perfectly plausible, they rest on the assumption that certain forms of conceptualization are more natural than others, and predict differences in processing difficulty as a function of linguistic factors. Langacker's claims, then, are exactly the sort of ideas that can and should be tested with empirical methods such as ERP experiments.

Indeed, Münte, Schiltz, & Kutas (1998) have used slow cortical potentials evident in recorded ERPs to address whether temporal iconicity affects the processing of language. Münte and colleagues hypothesized that people's conception of time as a sequential order of events determines the way we process statements referring to the temporal order of events. Consequently, they recorded ERPs as participants read sentences such as "Before/After the psychologist submitted the article, the journal changed its policy." Because, "Before X,Y" presents information in the reverse chronological order, it was hypothesized that these sentences would be more difficult to process than the "After" sentences. Indeed, Münte et al. found that ERPs recorded at electrode sites on the left frontal scalp were more negative for the more difficult "Before" sentences. Perhaps more compelling, they found that the size of this effect was correlated with individual participants' working memory spans. As noted above, individual differences that correlate with ERP effects may illuminate the functional significance of those effects in a way that bears on the original question. In this case, the data suggest that temporally iconic "after" sentences imposed less of a demand on working memory than did the less iconic "before" ones.

5. Considerations on ERP research

Although the previous section's review of cognitive linguistic ERP research was not necessarily exhaustive, it was fairly comprehensive. While intriguing, this handful of studies hardly constitutes a complete body of research. Although there are known limitations to using ERP data to localize neural generators in the brain, it is an excellent measure for determining precisely when the processing of two classes of stimuli begins to diverge. Because it can provide a continuous real time index of processing that occurs at the advent of a linguistic stimulus, the ERP is well-suited for addressing questions that have to do with what sorts of information experimental participants are sensitive to and when.

Because the N400 is sensitive to the same processes indirectly assessed in the reaction time paradigm, we can view its use in investigations of language comprehension as an analogous version of behavioral measures such as priming. One advantage of ERP measures, however, is that they can be collected in the absence of an explicit task (other than that of language comprehension itself). Moreover, ERP measures can also be collected while the participant performs a behavioral task, thus giving the experimenter a measure of on-going brain activity before, during, and after the performance of the task. Regardless of whether one conducts two experiments – one behavioral and one ERP – or, whether the two sorts of measures are collected together, ERP data can greatly aid in the interpretation of the behavioral results.

In fact, ERP and reaction time data are often complementary as reaction time data can provide an estimate of how long a given processing event took, while ERP data can suggest whether distinct processes were used in its generation. An experimental manipulation that produces a reaction time effect might produce two or more ERP effects, each of which is affected by different sorts of manipulations. By giving the experimenter the means to explore these dissociations, ERPs can help reveal the cognitive processes that underlie the linguistic phenomena of interest. In fact, because they can be identified with specific cognitive processes (e.g., meaning integration, working memory load, or the registration of an ungrammatical sentence), ERP effects provide evidence of how processing differs in the experimental conditions (King & Kutas 1995).

5.1 Constraints on ERP research

The basic ERP methodology in language research involves recording ERPs to minimally different sorts of language stimuli in order to observe modulations in the amplitude and/or latency of particular components. However, there are a number of constraints to keep in mind when designing an ERP experiment. First, the subject must remain relatively still during the recording of the EEG. Because the signal in the ERPs is very small (typically less than 10 microvolts), the bioamplifiers are extremely sensitive. Movement of the body can result in temporarily overloading the amplifiers.

Further, because the eye also has electrical properties, blinking and eye movements produce electrical activity that is detected by the EEG electrodes. While the brain is encased in the skull, the eyes are not. Consequently, voltage fluctuations due to eye movements can obscure the much more theoretically interesting brain activity. Although there are a few different mathematical techniques for isolating the contribution of the eyes to the EEG data, most ERP researchers deal with this problem by telling participants not to blink or move their eyes during critical points in the experiment, and by not including EEG corrupted by blinks or eye movements in the ERP.

The larynx also has electrical properties detectable by EEG electrodes so that it is not practical to record ERPs to the production of overt speech. What's more speech production can result in body motion that results in electrical noise and overloading the bioamplifiers. It is possible, however, to record ERPs to the onset of a stimulus for naming, such as a word or a picture. If naming latencies are short, the ERP elicited by the picture is likely to be corrupted by noise induced by speech onset. However, slightly longer naming latencies enable the researcher to collect artifact-free ERP. Although the ERP technique is more compatible with studying language comprehension, a number of researchers have developed paradigms for addressing issues in language production (see e.g. Jescheniak, Schriefers, Garrett, & Friederici 2002; Schmitt, Schlitz, Zaake, Kutas, & Münte 2001).

Another constraint to keep in mind is that – by definition – the ERP is the brain response to numerous stimuli that share some theoretically interesting property such as occurring in a true sentence rather than a false one, or being a prototypical category member as opposed to a non-prototypical one. For language experiments, a minimum of 30 trials in each experimental condition (that is, each "cell" in the design) is recommended to obtain a reasonable ratio of signal to noise. As several components of the ERP are sensitive to stimulus repetition (VanPetten 1991), most experimenters construct multiple stimulus lists in order to fully counterbalance their design without requiring individual subjects to read multiple versions of a single stimulus. Also, because ERPs can vary greatly between individuals, it is advisable to use a within-subjects design whenever possible. That is, all subjects should participate in (viz. read examples from) every condition so as to minimize the impact of individual differences on the experimental results.

Because ERPs require a discrete processing event for their elicitation, it is best if experimental effects are predicted to occur on a particular word or words in the sentence. In experiments where participants read the stimuli, sentences are usually presented one word at a time so that the ERP is time-locked to the critical word in the sentence. In experiments using spoken materials, it is important for the critical word or words to have a clear onset.

Recording ERPs to auditorally presented materials comes with its own set of challenges. Perhaps the main problem is that words in continuous speech do not generally elicit distinct ERPs because word boundaries are often absent from the speech signal. Fortunately, it is still possible to observe measurable differences in N400 amplitude to the last word of congruous and incongruous sentence completions (e.g. Holcomb & Neville 1990; Van Petten, Coulson, Rubin, Plante, & Parks 1999). Moreover, Müller and colleagues point to the utility of examining slow cortical potentials when investigating the comprehension of spoken language (Müller, King, & Kutas 1997). In a sentence processing study that compared ERPs elicited by subject-relative sentences with the more demanding object-relative sentences, Müller and colleagues identified an ultra-slow frontal positivity whose amplitude varied as a function of comprehension difficulty in both written and spoken materials.

Similarly, Steinhauer and colleagues (Steinhauer, Alter, & Friederici 1999) have used ERPs to study how intonational phrasing guides the initial analysis of sentence structure. They recorded ERPs as subjects listened to syntactically ambiguous sentences with appropriate and inappropriate prosodic cues. In naturalistic stimuli, Steinhauer and colleagues found that participants' ERPs showed a positive-going waveform at prosodic boundaries that they call the Closure Positive Shift. In cases where the prosodic cues conflicted with syntactic ones, the mismatch elicited an N400-P600 pattern of ERP components suggesting participants used prosodic features to determine their initial (incorrect) parse of the sentence. These results show that the ERP is a good measure for revealing the time course and neural basis of prosodic information. These factors could prove useful for the study of many topics in cognitive linguistics.

5.2 Future directions

One promising area for future ERP research is to test hypotheses stemming from the central tenet of cognitive linguistics that linguistic forms are often motivated by particular contrasts in meaning. For instance, though the distinction between count nouns (like cat and shoe) and mass nouns (like water and footwear) is arbitrary to an extent, it seems to be motivated by the way in which their referents are construed. While count nouns are typically used to denote unitary objects that can be individuated, mass nouns often denote homogeneous substances that are difficult or impossible to individuate. Interestingly, non-prototypical uses of mass nouns seem to support the idea that the count/mass noun distinction marks a difference in construal of the target object (Langacker 1987). For instance, uncooked potatoes are easy to individuate and function as count nouns. Mashed potatoes, however, form a homogeneous substance and can be referred to with a mass noun, as in (10).

(10) Could I please have some more potato?

The semantic motivation for the mass/count distinction might be tested by combining drawings or photographs that promote a particular construal of the target object with language stimuli that employ either a mass or a count noun. If the construal of the target object is relevant to the choice of a mass versus a count noun, any incompatibility between the construal promoted by the pictures and that promoted by the linguistic form ought to give rise to an ERP effect. One might present the pictures first and time-lock ERPs to the onset of a critical word in the sentences that employ mass vs. count nouns. Alternatively, one might present the language stimulus first, and time-lock ERPs to the onset of pictures that are either compatible or incompatible with the construal promoted by the preceding sentence.

The proposed combination of language and pictures would seem to be quite promising for cognitive linguistic research. Basic proposals about the importance of perspective and profiling in meanings constructed by speakers could be tested by contrasting ERPs to construal-appropriate and construal-inappropriate pictures. Similarly, photographs could be used to promote the activation of background knowledge from various domains to test the way in which it affects the interpretation of words with metaphoric, metonymic, or otherwise polysemic meanings.

Although cognitive neuroscientists have learned a great deal about language comprehension, it remains the case that most studies have employed experimenter-constructed stimuli in the controlled and artificial setting of the laboratory. Naturalistic language use can differ markedly from that employed in most scientific studies. Not only are the units of processing larger than those typically studied – that is, texts and discourses rather than the words and sentences so dear to the hearts of psycholinguists – but there are social and physical cues to guide the language user. In the future, we must exploit technological advances to bring more of the world into the laboratory. For instance, using mpeg (Moving Picture Experts Group audio Layer-3) technology it is possible to present subjects with auditory stimuli, such as naturally occurring conversation, or more controlled, scripted versions of the same phenomena.

Another facet of normal language comprehension typically absent from laboratory studies is the presence of visual information. This visual information includes both the local context as well as visual information about the speaker, such as her facial expressions and her gestures. As EEG can in principle be time-locked to the onset of visual events in MP3 videos, it is possible to record ERPs as subjects watch videos of speakers interacting in real contexts. Although the continuous nature of videographic stimuli present some of the same problems as continuous speech, it seems plausible that large differences in processing difficulty would be evident in ERP effect to visual stimuli, just as they are to speech.

Though we have seen that the 10% myth is false, and that the brain is ultimately an organ whose cells engage in a continual exchange of electrochemical signals, there is some truth to the idea that our brains harbor unharnessed potential for learning about all sorts of things – including brain function itself. As discussed in this chapter, electromagnetic changes in the brain can be detected with electrodes placed on the scalp. Remarkably, the ERP technique is sensitive to the cognitive operations involved in language comprehension and suitable for addressing various issues in cognitive linguistics. In particular, the on-going nature of the EEG signal makes it a good dependent measure for assessing the comprehension of linguistic materials in real time. We have discussed some of the ways in which ERPs have already been used to test ideas in cognitive linguistics, as well as some ways ERPs might potentially be used to do so in the future. Clearly, the use of ERPs in this way has not reached even 10% of its potential! In the end, investigation of these issues is limited only by the imagination of the experimenters.

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