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Electrophysiology and Pragmatic Language Comprehension

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1. Introduction

At the outset of their book RELEVANCE, Sperber & Wilson (Sperber, 1995) remind the reader, "In writing this book, we have not literally put our thoughts down on paper. What we have put down on paper are little dark marks, a copy of which you are now looking at. As for our thoughts, they remain where they always were, inside our brains." With these witty remarks, they note that while we often think and speak as if language were a conduit for thought, this is only a metaphor, and a deceptive one at that. It is deceptive because it implies that language comprehension can be reduced to a decoding process (Reddy, 1979). Another, perhaps more appropriate, metaphor involves a portrait of the language user as a paleontologist who constructs theories about extinct animals based on linguistic fossil input. But regardless of one's favorite metaphor for the relative import of coded and inferential aspects of language comprehension, recent advances in the study of language suggest that the many-headed beast we call meaning depends importantly on electrical activity in the brains of the speakers and hearers who construct it.

It might seem odd to suggest that pragmatics, as the study of language in context, should be investigated in the controlled conditions of the laboratory. Perhaps even more bizarre is the suggestion that pragmatics – the aspect of language comprehension that requires the appreciation of cultural conventions, that describes the expression of social relationships, and that frequently appeals to explanatory frameworks which transcend the individual – might profitably be studied with physiological methods. In answer to the first worry, we point to the other contributions in this volume. In answer to the second, we note pragmaticists' increasing appeal to inference in their accounts of how the listeners construct the speakers' intended message (Bach, 1994, Barwise, 1983, Carston, 1998, Fauconnier, 1997, Recanati, 1989, Sperber, 1995), and point to the importance of the brain for cognitive activity.

In cognitive neuroscience, language can be treated in three different ways: first as an overt behavior, second as an activity subserved by mental computation, and third as neural activity (Zigmond, 1999). Ultimately, the goal is to build a three-level account of pragmatic language competence that involves a description of the phenomena, a description of the cognitive processes or mental computations that underlie those phenomena, and a description of the neural activity that implements the cognitive processes (as in (Marr, 1982)). Due both to advances in technology and an increasing appreciation for the utility of establishing the link between cognitive processes and their neural implementation, recent years have seen a dramatic increase in the number of investigators using measures of neural activity to elucidate cognitive processes. One such measure is the event-related brain potential (ERP) derived from the electroencephalogram (EEG). A non-invasive measure of electrical brain activity, the ERP has proven to be a useful tool for studying cognitive and language processes. It provides a link to the neurobiology of behavior, it has a high temporal resolution, and it allows the investigator to draw inferences about qualitative and quantitative processing differences. Indeed, even investigators whose primary concern is in mental computations and who have little interest in the relationship between cognitive and neural processes can find this methodology useful as a multi-dimensional index of on-line language comprehension.

Below we review how electrophysiological methods and data can inform the study of pragmatic language comprehension. We begin with a general description of the EEG and ERPs, and give an overview of language sensitive ERP components. Findings from the cognitive ERP literature are discussed in a way intended to highlight how ERPs can be used to address questions about the representation and timing of cognitive processes, and how electrophysiological data can complement experimental findings using behavioral paradigms. Finally, we suggest how ERPs might be used to experimentally address issues pertaining to pragmatics such as the comprehension of direct versus indirect speech acts; the computation of entailments, explicatures, and implicatures; and the importance of non-linguistic cues for language comprehension.

2. EEG & 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 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 galvanometers to move pens 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.

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 EEG amplifies tiny electrical potentials and records them in patterns called brain waves. Brain waves vary according to a person's state, as different patterns can be observed when a person is alert and mentally active than when she is relaxed and calm, or than when she is sleeping. The pattern of electrical activity in the fully awake person is a mixture of many frequencies but is dominated by waves of relatively fast frequencies between 15 and 20 cylces per second (or Herz), 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 brain waves oscillating at a frequency that ranges from 9-12 Herz. As the subject falls asleep, her brainwaves will begin to include large-amplitude delta waves at a frequency of 1 Herz.

Although the EEG provides overall information about a person's mental state, it can tell us little about the brain's responses 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 motoric response (Hillyard, 1983, Rugg and Coles, 1995). As noted above, we obtain ERPs by recording subjects' EEG and averaging the brain response to stimulus events. For example, in early work on language processing, (Kutas and 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.

Although the EEG associated with the presentation of a single event is relatively inscrutable, cognitive neuroscientists have detected certain regularities in EEG elicited by sensible sentence completions (like "sugar" in (1)) that differ from those in EEG elicited by bizarre sentence completions (like "dog" in (2)). To date, the best method for highlighting these regularities in the EEG is to average the signal associated with a given category of stimulus. 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. 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.

For example, in their landmark study, Kutas & Hillyard constructed 70 sentences, half of which ended congruously, half incongruously (Kutas and 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 et al., 2000a) 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 which is slightly larger over the right side of the head.

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. While exogenous components are modulated by the intensity, frequency, and duration of the stimulus events, endogenous components are modulated by task demands and other manipulations that affect the subjects' expectancies, strategies, and mental set.

The P300 component of the ERP is a paradigmatic example of an endogenous component because its amplitude (or size) is modulated by subjective aspects of experimental stimuli, such as their salience, their task relevance, and their probability. Actually a whole family of positive-going components of varying latency, 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, 1978, Kutas, 1977, Magliero, 1984, McCarthy, 1981, Ritter, 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 one statement, and then asked to signal whether another statement was entailed or implied by the first. 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. 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.

3 Language Sensitive ERPs

Since the discovery of the N400, cognitive neuroscientists interested in language have frequently appealed to ERPs as a dependant measure in psycholinguistic experiments. As a result, a number of language-sensitive ERP components have been reported (see (Kutas et al., 2000b) for review). Although most of this research has been motivated by issues in sentence processing, these findings may prove valuable to researchers interested in pragmatic aspects of language comprehension. 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 pragmatic language comprehension.

3.1 N400

The N400 is a negative-going wave evident between 200 and 700 ms after the 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 than the left (Kutas, 1988). The N400 is elicited by words in all modalities, whether written, spoken, or signed (Holcomb, 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 and 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, VanPetten, 1991a). Further, while pseudowords (orthographically legal letter strings) elicit even larger N400s than do real words, orthographically illegal nonwords elicit no N400 at all (Kutas and Hillyard, 1980).

In addition to its sensitivity to lexical factors, the N400 is sensitive to contextual factors related to meaning. For exampe, one of the best predictors of N400 amplitude for a word in a given sentence is that word's cloze probability (Kutas, 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 N400 is an ERP component elicited by sentence final words. However, N400 is 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 (VanPetten, 1991b). 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.

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, 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, 1992). However, subsequent testing indicated that word class effects are attributable to quantitative differences in word length and frequency (Osterhout, 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, 1998). Because its latency is sensitive to word frequency, this component is useful as an index 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 dependancies that required the maintenance of information in working memory during parsing (Kluender, 1993). Similarly, King & Kutas (King, 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, sometimes called the syntactic positive shift (SPS). This slow positive shift has been elicited by violations of agreement, phrase structure, and subcategorization in English, German, and Dutch (Coulson et al., 1998b, Hagoort, 1993, Mecklinger, 1995, Neville, 1991, Osterhout, 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, although anterior effects have also been reported (see (Coulson et al., 1998b) 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, 1999).

However, Coulson and colleagues (Coulson et al., 1998b) found that the amplitude of the P600 varied with the probability of ungrammatical trials within an experimental block. In fact, the P600 to all improbable trials (collapsed across grammaticality) was indistinguishable from that to all grammatical violations. Thus Coulson et al. (Coulson et al., 1998b, Coulson et al., 1998a) argue 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 environment (Donchin, 1988). Nonetheless, the fact that syntactic violations are associated with the late positive ERP known as the P600 provides a convenient tool for testing hypotheses about grammatical processing and its impact (or, perhaps even dependence) on contextual, pragmatic factors.

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 Hertz. Kutas describes three slow brain potentials which might be elicited in experimental studies of the comprehension of pragmatic aspects of written language (Kutas, 1997). The first is a left lateralized negative shift over occipital sites that is 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 sentential integration. Since inferential aspects of language comprehension might be expected to develop slowly over the course of a sentence, or set of sentences, it is likely that experimental manipulations that promote or inhibit the generation of inferences might be detected as modulations of these slow cortical potentials.

4. ERP studies of pragmatic language comprehension

Because it can provide a continuous on-line 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. One constraint to keep in mind, however, is that (by definition) the ERP is the brain response to numerous stimuli that share some theoretically interesting property such as occuring 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 (viz. each cell) is recommended to obtain a reasonable ratio of signal to noise. As several components of the ERP are sensitive to stimulus repetition (VanPetten, 1991a), most experimenters construct multiple stimulus lists in order to fully counterbalance their designs without requiring individual subjects to read multiple "versions" of a single stimulus. Finally, because ERPs can vary greatly between individuals, it is advisable to use a within-subjects design whenever possible.

Given these caveats, there are a number of ways to use ERPs to test hypotheses about language comprehension. For instance, given the assumption that qualitative differences in the ERP waveform reflect the operation of qualitatively different cognitive processes, ERPs can be used to identify the operation of different cognitive processes as they occur in the interpretation of langauge. One possible use of the ERP measure, then, would be to identify different components in the waveforms that index different levels of processing. For example, the existence of separate components in the waveform that index functionally distinct levels of processing could be seen as implicit support for a firm distinction between semantics and pragmatics. Moreover, once identified, electrophysiological indices of semantic and pragmatic processing could be used to test hypotheses about the relative contribution of each to the comprehension of any given linguistic stimulus.

To date, very little ERP language research has concerned pragmatic aspects of language comprehension. Moreover, the little that has been done has not revealed an ERP index specifically sensitive to pragmatic language comprehension. However, extant work has suggested that ERPs are sensitive to experimental modulations of higher level contextual factors. For example, St. Georges, Mannes, & Hoffman recorded participants' ERPs as they read ambiguous paragraphs that either were or were not preceded by a disambiguating title (St. George, 1994). Although the local contextual clues provided by the paragraphs were identical in the titled and untitled conditions, words in the untitled paragraphs elicited greater amplitude N400s.

Similarly, Van Berkum, Hagoort, & Brown found that words which elicit N400s of approximately equal amplitude in an isolated sentence, do not elicit equivalent N400s when they occur in a context that makes one version more plausible than the other (VanBerkum, 1999) . For instance, "quick" and "slow" elicit similar N400s in "Jane told her brother that he was exceptionally quick/slow." However, "slow" elicits a much larger N400 when this same sentence is preceded by "By five in the morning, Jane's brother had already showered and had even gotten dressed." This sensitivity of the N400 component to higher-order aspects of language makes it an excellent measure for testing hypotheses about processing difficulty associated with the comprehension of various sorts of pragmatic language phenomena.

Muente, Schlitz, & Kutas have used slow cortical potentials evident in recorded ERPs to reveal processing differences between superficially similar sentences that required readers to differentially exploit their background knowledge (Munte, 1998). Muente 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, Muente 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.

4.1 Considerations in ERP Language Research

The basic paradigm in ERP language research involves recording ERPs to (minimally) different sorts of langauge stimuli in order to observe modulations in the amplitude and/or latency of particular components. 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 brain wave measures are acquired with a high degree of temporal resolution (on the order of milliseconds), ERPs can potentially reveal the exact moment of divergence in the processing of particular categories of events. In any case, the detection at time *t* of a reliable difference in the ERP waveforms elicited by two categories of events suggests that processing of those categories differs at that instant, and began at least by time *t* (Coles, 1990).

Because the N400 is sensitive to the same processes indirectly assessed in the reaction time paradigm, we can view its use in investigations of pragmatic langauge comprehension as an analogous version of behavioral measures. One advantage of ERP measures 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 concomitantly, 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 pragmatic phenomenon of interest. In fact, to the extent that ERP effects can be identified with specific cognitive processes, they provide some evidence of how processing differed in the different conditions (King, 1995).

4.2 Joke Comprehension

Joke comprehension is one area of language comprehension relevant for pragmatics because of the way it highlights the importance of background knowledge for comprehension and the development of expectations. For example, "I let my accountant do my taxes because it saves time: last spring it saved me ten years," is funny both because the reader or listener initially expects the amount of time saved by the accountant to be on a different order of magnitude than years, and because it is possible to formulate a coherent interpretation of the statement whereby the "time saved" is jail time. While lexical reinterpretation plays an important part in joke comprehension, to truly appreciate this joke it is necessary to recruit background knowledge about the 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 pragmatic reanalysis needed to understand examples like this one as *frame-shifting* (Coulson, 2000).

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 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. Accordingly, Coulson & Kutas measured how long it took people to read sentences that ended with jokes that required frame-shifting than with non-funny "straight" endings consistent with the contextually evoked frame (Coulson, 1998). 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% to 5%. Coulson & Kutas 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 (Coulson, 1998). 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 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 (Coulson and Kutas, 2001). 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 endings elicited a larger N400 (300-500 ms post-onset) than the straights. Also, in this group, both sorts of jokes (high and low constraint) elicited a 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 suggests 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, 1998). ERP results suggested the processing cost associated with frame-shifting is related to higher-level processing (Coulson and Kutas, 2001). In the case of the high constraint jokes, the difficulty includes the lexical integration process 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 the 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, and their relationship to various pragmatic phenomena has a great deal of potential. Experimental approaches to pragmatics, especially when the topic concerns whether readers generate inferences in response to certain sorts of contextual cues, would do well to consider how individual differences in cognitive abilities affect these phenomena. Moreover, work on joke comprehension by Coulson and Kutas demonstrates how ERPs and reaction time data for the same stimuli can provide complementary information about the underlying cognitive processes.

4.3 Metaphor Comprehension

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 pragmatics 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 to comprehend, but that the latter required more effort or processing resources. Alternatively, comprehension processes for literal versus metaphoric utterances might take the same amount of time to complete, and yet involve quite different computations (Gibbs, 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, 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 nonliteral 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 and Matlock, 2001, Gibbs, 1994, Giora, 1997, Glucksberg, 1998). Coulson's (2000) 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, in press) 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 one 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 (Coulson, in press) 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 waveshape 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.

5. Future Directions

While a few ERP studies of figurative language comprehension have been conducted, serious investigation of the pragmatic aspects of language comprehension has barely begun. This is no easy task as understanding language as an integrated, goal-directed process will require elucidating the relationships that hold among language subcomponents and between language and other cognitive abilities. For instance, understanding language utterances necessarily requires that relevant linguistic, contextual and background knowledge be integrated. However, very little is known about the relative importance of local context and background knowledge, or how these factors interact. Because different components of the brain waves are modulated by different factors, ERPs are a potentially powerful tool for teasing apart the different contributions of linguistic and non-linguistic sources of information.

5.1 Direct versus Indirect Speech Acts

For example, ERPs could be recorded while a subject read or listened to sentences that constituted either direct or indirect speech acts as in (7) and (8). The effect of posing the speech act as a question might be assessed by including a contrast between a direct interrogative speech act posed as a question (as in (9)) and an indirect speech act posed in a declarative sentence (as in (10)).

(7 Give me the mustard.
(8) Can you give me the mustard?
(9) Did Harry marry Sally?
(10) I'd like to know if Harry married Sally.

By recording ERPs to words in direct and indirect speech acts it is possible to observe whether one form of these speech acts is easier to process and whether the relative processing difficulty can be altered by varying the contextual conditions in which they occur.

5.2 Entailments, Explicatures, and Implicatures

One issue in pragmatics to which ERP research might be productively directed is the distinction between explicatures, implicatures, and entailments. In the framework of relevance theory (Sperber, 1995), the *explicature* is a fully specified linguistic meaning of an utterance, an *implicature* is an implicit inferred meaning of an utterance, and an *entailment* is a proposition that is logically implied by the sentence. For example, in a context in which the speaker has been asked about how many people went to the Cognitive Science Holiday Party, the explicature of (11) is akin to "Not all of the people invited to the Cognitive Science Holiday Party went to the Cognitive Science Holiday Party."

(11) All of the boys went to the party.

(12) Some of the boys went to the party.

(13) Not all of the boys went to the party.

In this context, (12) is entailed by (11), because it is true in all situations in which (11) is true. Interestingly, the speaker who asserts (12) implicates (13) but does not entail it, as (truth-functionally) (12) is true when (11) is and (11) and (13) are mutually incompatible.

By recording ERPs to explicatures, implicatures, and entailments it might be possible to detect whether these categories of language-induced inferences elicit the same pattern of brain waves. ERPs could also be used to evaluate the adequacy of pragmatic theories by testing whether or not the same processes underlie the derivation of explicatures and implicatures, or whether certain sorts of information is derived automatically. For example, one might, as Gibbs and Moise did with behavioral measures (Gibbs, 1997), ask readers to judge what a speaker says when he asserts “Jane has 3 children,” and compare ERPs elicited by the minimal meaning “Jane has at least three children but may have more than three,” and the enriched meaning “Jane has exactly three children and no more than three,” to see which category elicits more signs of surprise and/or processing difficulty.

5.4 The importance of non-linguistic cues for language comprehension

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. However, language "in the wild" occurs in a much richer context. 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 MP3 technology it is possible to present subjects with auditory stimuli, such as naturally occurring conversation, or more controlled, scripted versions of the same phenomena. EEG could be collected while subjects listened to these stimuli, and ERPs to theoretically interesting events could be examined.

The on-going nature of the EEG signal makes it a good measure for assessing the on-line comprehension of linguistic materials. However, recording ERPs to auditorally presented stimuli 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 possible nonetheless to observe measurable differences in N400 amplitude to the last word of congruous and incongruous sentence completions (e.g. (Holcomb, 1991, VanPetten, 1999). Moreover, Mueller and colleagues point to the utility of examining slow brain potentials when investigating the comprehension of spoken language (Muller, 1997). In a sentence processing study that compared ERPs elicited by subject-relative sentences with the more demanding object-relative sentences, Mueller et al. identified an ultra-slow frontal positivity whose amplitude varied as a function of comprehension difficulty in both written and spoken materials.

Similarly, Steinhauer, Alter, & Friederici have used ERPs to study how intonational phrasing guides the initial analysis of sentence structure (Steinhauer, 1999). 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 phrase 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 intial (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 processing.

It seems possible that the ERP effects that proved useful for sentence processing studies by Mueller (Muller, 1997) and Steinhauer (Steinhauer, 1999) might also prove useful in elucidating the pragmatic import of prosodic intonation. For example, ERPs could be recorded as subjects listen to sentences such as (14) intoned as promises or as threats.

(14) I'll be there.

Moreover, such sentences could be embedded in contexts which are either appropriate or inappropriate in order to compare the time course of semantic and prosodic information on the ERP. Similarly, our intonational promises and threats could be embedded in contexts that vary in the degree to which they disambiguate the speech act in order to explore the interaction of semantic and prosodic variables on ERP indices of on-line language comprehension.

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 effects to visual stimuli, just as they are to speech.

6. Conclusion

As noted in the introduction, the study of pragmatics can never be totally divorced from the observation of language use in naturally arising communicative contexts. However, if we hope to develop a science that extends beyond the scope of the ethnographic site, it is important to test the generalizability of hypotheses in pragmatics with other tools in the cognitive scientist's toolbox, including native speaker intuitions, reaction times and accuracies on various judgment tasks, eye movement registration, and, even, scalp recorded ERPs. This chapter has reviewed how ERPs are recorded, outlined the strengths and weaknesses of the technique, discussed what sorts of linguistic manipulations are known to give rise to ERP effects, and offered suggestions as to how the technique could be applied to address issues in pragmatic language comprehension. Just as the meaning of an utterance cannot be simply decoded, the significance of an ERP effect requires consideration of the motivating hypotheses, the experimental design, and knowledge of the sorts of manipulations that have led to similar effects in the past. Hopefully the reader who has made it this far has gleaned enough about the use of the ERP technique to see its power and utility for studying the inferential comprehension processes so essential for pragmatics.

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