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CHAPTER 3

Electrophysiological insights into language deficits

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Neurolinguistics revisited

The human language processor

The human capacity for communication by means of a natural language is undoubtedly one of the most complex products of evolution. Most people seem to speak and listen effortlessly. And, yet, both psycholinguistic and neuropsychological research attest to the diverse set of representations that are accessed or constructed anew during ordinary language comprehension and production. Moreover, these access and construction processes are executed with amazing speed. For instance, adults can readily produce up to 15 speech sounds per second (Levelt, 1989) and can, on average, recognize a word in conversation (i.e. in context) within 200 ms (Marslen-Wilson, 1989). Thus, during both speaking and listening, the average adult manages quickly and unconsciously to gain access to the phonological, morphological, syntactic and semantic information that is appropriate for a particular lexical entry (i.e. word) from a database of between 40 000 and 70 000 words (Nagy and Herman, 1987). Clearly, the high speed with which word information is accessed imposes very strong constraints on the viability of any theory of the representational structure of the mental lexicon and the mechanism(s) that provide(s) access to it.

Lexical access, however, is but one operation among the many that are essential for effective communication via language. Understanding speech is not simply a matter of accessing word forms. Once the acoustic stream has been segmented into units that access existing word forms, the language processor is faced with the task of combining the syntactic (e.g. word class and for verbs, argument structure) and semantic information associated with each word form in a way that is consonant with the speaker's intent. That is, recently accessed syntactic and semantic information have to be integrated with the representation of the 'meaning' of the utterance that is most consistent with all the available information up to that moment; this process of mapping the lexical information onto the intended meaning of the whole utterance is called lexical integration (Marslen-Wilson, 1984). It is likely that lexical integration is guided both by local constraints provided by recently accessed word forms and by the global constraints of the ongoing conversation or discourse; the latter must in turn be shaped by the overall context and pragmatics of the situation.

In a variety of models that differ in other regards, the parser is credited with a central role in lexical integration. Specifically, it has been suggested that it is the parser that assigns each word in an incoming string its grammatical role in the sentence (cf. Frazier, 1987). Lexical integration also subsumes whatever mechanism assigns the different sentence constituents their thematic roles (e.g. agent, experiencer, theme), undeniably a necessary precursor to successful interpretation of a grammatical utterance. Whereas most models of language comprehension honor the need for a functional distinction between lexical access and lexical integration, considerable controversy still surrounds the question of whether and, if so, how these processes influence each other in real-time (cf. Frauenfelder and

Tyler, 1987). In fact this is one of the most active areas of psycholinguistic research.

Theoretical and empirical accounts similar to those for speaking and listening could be provided for their evolutionary derivatives, writing and reading. In short, current theories of the cognitive architecture of these complex language skills typically comprise a number of declarative knowledge structures and a host of processing components that operate on these structures. Thus, a full specification of the cognitive architecture(s) that subserve(s) these different language functions requires: (i) characterizations of the different representations that are computed by the different processing components; (ii) delineation of how these representations are computed in real-time; and (iii) specification of how the various processing components cooperate with each other to generate their joint end product (cf. Levelt, 1989).

In the remainder of this chapter we discuss issues central to an understanding of the breakdown of language skills consequent to various types of brain damage. We start with arguments as to why recording of event-related brain potentials (ERPs) during distinct language events in patients with specific language deficits can help to elucidate the nature of processing in a compromised language system and by inference in an intact system. We follow with a short overview of the several ERP components (e.g. N400, N280-410, N400-700, P600, syntactic positive shift or SPS) that are most relevant[1] to investigations of normal language processing. We continue by raising some of the methodological concerns that routinely plague researchers collecting electrophysiological data from brain-damaged patients. We conclude with a brief synopsis and critique of ERP studies of patients characterized by some language disturbance. Note that this review is not exhaustive; rather it focuses on those ERP investigations of language disintegration that in our opinion are most directly driven by important theoretical issues within cognitive neurolinguistics or that exemplify one or more of the methodological concerns that arise in ERP studies with brain-damaged patients.

The case for cognitive neurolinguistics

Aside from the obvious aim of systematically characterizing language impairments in neurological patients, a major goal of cognitive neurolinguistics is to use various 'experiments of nature' to support inferences about the cognitive architecture underlying normal, human language performance (cf. Ellis and Young, 1988). The likelihood that inferences about the intact system can be drawn from the performance of the failing system is a function of the extent to which the identical cognitive architecture can be used (with contortions) to account for normal as well as aberrant language functions. This use of neuropsychological data is based on the assumption that the cognitive deficits consequent to brain damage can be understood in terms of the self-same cognitive architecture that routinely subserves the particular mental function (e.g. speaking or listening) under investigation (Shallice, 1988). This assumption is common to research in many domains of cognitive neuropsychology. It presupposes that brain-damaged patients fortuitously accommodate researchers with impairments to relatively isolable knowledge structures or processing components. However, as discussed at length by Caramazza (1984, 1986, 1992), data from brain-damaged individuals can only constrain models of normal cognition if the consequences of the insult to the cognitive architecture are 'local'. If the brain injury has a more 'global' impact that leads to functional reorganization of the cognitive architecture or to the creation of a new architecture for the particular function at issue, then the range of valid inferences about the normal functioning of the system that can be drawn from the deficits displayed by the brain-damaged patients is severely limited (Caramazza, 1992). Whether or not, or for what syndromes this locality assumption holds is at the crux of a heated and ongoing debate in the neuropsychological literature (cf. Caramazza, 1992; Farah, 1994; Kosslyn and Intriligator, 1992; Kosslyn and Van Kleeck, 1990; Shallice, 1988).

For our present purposes, we remain neutral on this issue. Nevertheless, we cannot overemphasize our belief that the interpretation of neuropsychological data is critically dependent on the assumptions one

[1] Albeit not necessarily specific to language processing.

holds about the implications of damage to a neural substrate for the functional organization of a suboptimal cognitive function.

Two issues that are central to research in cognitive neurolinguistics are: (1) the nature of the impairment to particular language functions and (2) language-brain relationships (Caplan, 1987). We discuss each in turn.

Unlike researchers of normal language processing, those who study patient populations cannot take for granted that the output of the language processing system is more or less adequate relative to the input. That is, a specification of the ways in which words are accessed or syntactic structures are computed, etc. is not sufficient. We have first to determine in what respects the representations that are accessed or computed during comprehension or production deviate from normal. In addition, we have to explain what it is during the production/comprehension process(es) that cause(s) these intermediate and final representations to deviate from normal. Thus, in order to pinpoint the functional locus of an impairment in language comprehension and/or production, the following issues have to be addressed. First, it is necessary to determine whether the symptoms are specific to some aspect of language processing or whether they are the sequelae to a more general cognitive deficit; if the former, to determine which types of linguistic representations can no longer be accessed or computed, and thirdly, to ascertain whether this inability is due to the disintegration of declarative knowledge structures such as the mental lexicon, or to a reproducible glitch in the processing components that access and/or coordinate these knowledge structures in real-time. Naturally, the exact nature of these impairments also needs to be specified.

Traditionally, neurolinguists have hypothesized about which representations are missing, distorted or inaccessible in aphasic or dyslexic individuals from the patterns of spontaneously occurring or evoked errors that such patients produce. Thereby, impaired performance is used not only to define a patient's language deficit, but also to evaluate the resulting model of the intact language processing system. More specifically, it is often the specific pattern of associations and dissociations in the errors that patients produce that serves as the nidus of hypotheses about which declarative knowledge systems and input–output functions are normally involved in language processing. In this way, cognitive neuropsychology has contributed significantly to the development of detailed models of complex language skills such as reading (e.g. Patterson, Marshall and Coltheart, 1985; Patterson and Shewell, 1987).

Much of the data on which these models are based were collected employing paradigms wherein patients with language deficits were asked to: (1) match sentences with pictures; (2) manipulate toy objects in accordance with a linguistic description provided by the experimenter; (3) name objects; (4) complete a phrase or a sentence with a missing word; (5) rearrange a set of randomly presented sentence elements in a grammatically correct way; and (6) make an explicit judgement with respect to some aspect of the linguistic materials such as their grammaticality or meaningfulness. All of these are by their nature off-line tasks; in other words, patients are requested to operate on the final product of language comprehension or production processes. Clearly, such responses are not very tightly synchronized to the linguistic analyses prior to the final output or response. For instance, all of these tasks are relatively silent on the processes involved in lexical access or in the construction of a syntactic or semantic representation of a written passage or spoken utterance. Neuropsychological contributions to the isolation of critical language functions notwithstanding, the over-reliance on off-line tasks by cognitive neurolinguists has inadvertently created a blind spot for any explanation of language impairments due to modifications of the real-time processing characteristics of language. We think that potential dysfunctions in the real-time exploitation of language-relevant knowledge sources can only be examined through the application of on-line and real-time research methods, which are part and parcel of psycholinguistic research with normal subjects today. Well known examples include the lexical decision task (LDT) wherein subjects are required to decide as quickly as possible whether or not a string of letters or sounds forms a word of his/her native language, and the word monitoring task wherein subjects respond as quickly as possible to the occurrence of a previously specified word. In these tasks, inferences are based primarily on the differential patterns of reaction times for different experimental conditions.

Recent applications of these on-line techniques to aphasia research (e.g. Blumstein, Milberg and Shrier, 1982; Friederici, 1983, 1985; Milberg, Blumstein and Dworetzky, 1987, 1988; Baum, 1988, 1989; Friederici and Kilborn, 1989; Hagoort, 1989, 1990, 1993; Swinney, Zurif and Nicol, 1989; Haarmann and Kolk, 1991b; Tyler, 1992) have implicated alterations in the normal time course of language-relevant processes in a significant number of aphasic patients with comprehension deficits (e.g. Friederici and Kilborn, 1989; Swinney et al., 1989; Hagoort, 1990; Haarmann and Kolk, 1991b). Moreover, the results of several computational models of language impairments in both Broca's and Wernicke's aphasia have further corroborated the claim by Lenneberg (1967, p. 218) that 'almost all of the central nervous system disorders of speech and language may be characterized as disorders of timing mechanisms' (Haarmann and Kolk, 1991a; Miyake, Carpenter and Just, 1994). Last but not least, it has been suggested that the language problems of developmental dyslexics may likewise stem from some abnormality in the 'timing' mechanisms necessary for normal language processing (Tallal, Sainburg and Jernigan, 1991).

In mentioning these recent studies, it is by no means our intent to claim that all language deficits in neurological patients can or should be attributed to changes in the temporal organization of comprehension and/or production operations. What these findings do illustrate, however, is that changes in the temporal organization of mental operations that are essential to language are, on occasion, sufficient to cause certain language deficits and must therefore be ruled out before an alternative account of the deficit is rendered. On this view, complementing the traditional off-line procedures with on-line methods can only increase the precision of the proposed models of the language system and its disintegration. In the remainder of this chapter, we argue that the ERP is an on-line, real-time measure par excellence that can be fruitfully employed in neurolinguistic studies, provided that the ERPs are recorded to (linguistic) materials chosen specifically to tap the very aspect of the language system that has been hypothesized to be at the core of the impairment.

In addition to constraining theories of the cognitive architecture of language, another aim of cognitive neurolinguistics is to contribute to our understanding of the way in which the cognitive architecture of distinct language skills is implemented in the brain. Classically, this has been pursued by assigning the lost language function to the lesioned brain area (cf. Caplan, 1987). The potential success of this approach, however, hinges on the validity of the locality assumption. In addition, it depends critically on the assumption that the appropriate mapping between the cognitive architecture of a function and the neural organization underlying it is at the level of the gross anatomy of brain structures.[2] However, even a cursory survey of the literature on aphasia reveals relatively weak correlations between specific linguistic deficits and lesion site (e.g. Poeck, De Bleser and Keyserlingk, 1984; Basso, Lecours, Moraschini et al., 1985; Caplan, Baker and Dehaut, 1985). To us these observations portend the need for a new construal wherein the description of cognitive architecture of language production and comprehension in terms of its neural underpinnings is not in terms of gross anatomical structures. Perhaps, functions should be linked to the activity of neuronal networks, with lesions to different parts of the network yielding similar behavioral symptoms. Since scalp-recorded ERPs reflect the sum of simultaneous post-synaptic activity of many neurons, they are, in principle, a good candidate for establishing cognition-brain relationships. On this view, language-related ERP components are likely to reflect the activity of neuronal networks underlying a specific subsystem in the cognitive architecture of a particular function such as language comprehension.

For the time being using ERPs explicitly for this purpose is limited by the 'inverse problem'; i.e. that in principle, the distribution of electrical activity re-

[2]There is an additional implicit assumption that the structure-to-function mapping is one-to-one, and conversely.

corded at the scalp surface does not afford a unique solution to the location of the neuronal ensembles that generated them. However, over the past few years it has been shown that the space of possible solutions can be significantly reduced with the addition of a few anatomical and timing constraints and a substantial increase in the number of recording electrodes (e.g. Scherg, 1990; Dale and Sereno, 1993). Clearly, neuropsychological data will be of great benefit in providing some of the needed anatomical constraints. However, as our current knowledge of the neural substrates underlying language-related ERPs is relatively limited (see Chapter 10, this volume), in the remainder of this chapter we concentrate on how ERPs have contributed to establishing functional rather than anatomical loci of language impairments.

The case for ERPs in cognitive neurolinguistics

ERPs have several characteristics that make them especially well suited for addressing issues central to cognitive neurolinguistics. One important characteristic in this respect is the *multidimensional* nature of the ERP waveform. ERPs can vary along a number of dimensions; specifically, latency (time relative to stimulus onset at which an ERP component occurs), polarity (positive or negative), amplitude and amplitude distribution across the recording sites (i.e. scalp distributions). Thus, in principle, ERPs can reflect not just quantitative fluctuations in some process but the activity of qualitatively different processing events as well. Recent evidence, for instance, suggests that semantic and certain classes of syntactic violations elicit different patterns of ERPs, most likely reflecting the engagement of qualitatively different processing (and/or neural) systems (see below). Insofar as some ERP measure can be taken as a definitive sign that different linguistic representations have been accessed or computed, the results can be used to draw inferences about the level of linguistic representation that is affected in a particular patient population. For example, it has been claimed that agrammatic aphasics are selectively impaired in assigning a syntactic structure to an incoming string of words (e.g. Caramazza and Zurif, 1976). If this is the case, ERPs related to various aspects of syntactic processing should be more affected than other language-related componentry and should be most deviant in the agrammatic comprehenders. In general, then, selective changes in ERP components that seem to honor relevant distinctions in the cognitive architecture of language processing, can provide insights into which types of representations are most severely affected in patients with language problems.

The ERP has the added propitious characteristics of being both a *continuous* and a *real-time* measure. Like speeded reaction time (RT) measures in traditional psycholinguistic tasks such as naming, lexical decision, word monitoring, etc., ERPs elicited by words or sentences are tightly linked to the timing of language processing events.[3] But, in contrast to RT measures which are punctate, ERPs provide a continuous record of processing over periods that are co-extensive with the linguistic stimulation and beyond. It is thereby possible to monitor the immediate consequences of a particular experimental manipulation (e.g. a syntactic or semantic violation) as well as its downstream effects, if any. The continuous on-line nature of ERP recordings makes them a useful tool for testing recent claims that language deficits in aphasic patients and in developmental dyslexics are due to changes in the temporal organization of lexical access and lexical integration processes (e.g. Kolk and Van Grunsven, 1985; Friederici and Kilborn, 1989; Swinney et al., 1989; Hagoort, 1990, 1993; Haarmann and Kolk, 1991b; Livingstone, Rosen, Drislane et al., 1991; Tallal et al., 1991).

Another characteristic of the ERP-method that is especially fortuitous for neurolinguistic investigations is that reliable ERP effects can be obtained even in the *absence of any additional task* over and above the natural one of listening to spoken materials or reading written materials. This advantage is obvious when testing patients with severe comprehension deficits who attempt to read or listen to language materials by habit but do not always understand (the instructions or requirements for) more artificial additional or secondary tasks. Generally, the absence of an additional task

[3] At least to the onset of the relevant processing events on a trial-by-trial basis.

makes it easier to test patients with severe comprehension difficulties. The absence of an additional task also prevents its interference with the language processes under study. Recent ERP research has shown that reliable ERP effects can be obtained from aphasic patients merely listening to word pairs or sentences (Hagoort, Brown and Swaab, 1991, 1993; Swaab, Brown and Hagoort, 1991).

In our opinion these four characteristics of the technique (multidimensionality, continuity, on-line, efficacy without any additional task) make the ERP a powerful index of various language processes in brain-damaged patients, provided that the studies are neurolinguistically motivated and designed with necessary methodological precautions in mind.

Language related ERP components

A sizeable literature attests to the possibility of tracking various aspects of the language processing in individuals with ERPs in experimental situations that are relatively natural and undemanding in and of themselves (as long as we stipulate that remaining relatively motion-free is undemanding). More specifically, it is now possible to record the brain's response to individual words systematically varied along certain lexical dimensions, to words paired according to various orthographic, phonological, and semantic relations, and to phrases and sentences of varying levels of structural complexity. Moreover, it is possible to scrutinize the ERPs to language materials as subjects listen over headphones or read words flashed on a CRT; the subject's only task being to understand. Naturally, in many cases other tasks are imposed; the point, however, being that other tasks are not necessary to yield reliable electrophysiological data. For patients suffering the consequences of focal brain lesion due to stroke or more insidious pathological conditions, listening or reading alone constitutes a sufficiently heavy processing load obviating any further task demands.

A variety of paradigms have been used to assess different aspects of language processing electrophysiologically. Of course, the choices of the linguistic level of analysis and the associated paradigms are a natural outcome of the data being sought and the theoretical question at hand as well as the limitations of the patient group under study. Before detailing any patient studies, we overview the extant data on the electrophysiology of normal language processing. The literature on electrophysiological measures of speech processing is small but growing steadily. By contrast, there is a wealth of data on processing of written words in isolation, in wordpairs, in phrases and sentence fragments, in lists of isolated sentences, and in coherent text.[4]

The average ERPs to a visually presented word comprise a series of so-called exogenous components such as the P1, N1 and P2 as well as a number of endogenous components including the N280, N400, and various longer duration negative and positive shifts. Over the front of the head, the primary exogenous components are an N1 (between 80 and 180 ms) and a P2 (between 180 and 250 ms).[5] The P2 can be seen across the head but is larger over the fronto-central leads. Over the back of the head (e.g. occipital and temporal leads), the early components include a P1 component (60–120 ms) and N1 (150–200 ms) component. Not all subjects show the P1 perhaps because of the orientations of the generators relative to the electrode sites. The P1 component is usually asymmetric, being larger over the right than the left hemisphere. In addition to their sensitivity to physical stimulus parameters (such as intensity, duration, contrast, rate of presentation, etc.), these early components also show amplitude variation with various attentional manipulations (Mangun and Hillyard, 1990).

Auditorily-presented words evoke a broadly distributed N1 (80–180 ms) and a small P2 component (180–220 ms) followed by a large, slow negative-going component (300–800 ms). As in the visual mo-

[4]The following description of ERPs elicited by written words must be tempered with the realization that the exact pattern of ERP componentry elicited is determined not only by the physical stimulus and its features, but also some combination of task requirements, active recording sites, amplifier bandpass, and reference electrode (see Chapter 1, this volume).

[5]Analyses of scalp distributions of the ERPs in the first few hundred milliseconds suggest that both the P1 and N1 have several subcomponents, each with slightly different topographic profiles. Thus far, little is known, however, about the functional nature of the different subcomponents.

dality, the N1 and P2 components vary in amplitude and peak latency with stimulus parameters such as intensity, frequency, rate of presentation and attentional manipulations much like responses to non-verbal stimuli (Näätänen and Picton, 1987). Figure 1 shows the basic waveforms for visually and auditorily presented words (from Holcomb and Neville, 1990).

ERPs to words in isolation

The ERP waveforms elicited by words in isolation or various contexts are remarkably similar. While they do not differ very much in waveshape (morphology), they do exhibit systematic variation in either the amplitude and/or the latency of some of the components, especially the later ones. Indeed, it is the systematic variation in these parameters of the ERPs to various psychological and linguistic variables that allows their use in psycholinguistic and neurolinguistic experiments.

Clearly, before ERPs can be used to test different models of lexical processing in intact or brain-damaged individuals, it is essential to determine whether and, if so, how any given lexical attribute is manifest in the associated ERP. A brief summary follows.

One obvious question is whether the ERPs to letter strings that have meaning are different than to those that do not. That is, what is the nature of the difference, if any, to words, true non-words (i.e. unpronounceable strings of illegal letter combinations), and so-called pseudowords (pronounceable letter string combinations)? Results reveal that the ERPs to words and pseudowords (orthographically legal, pronounceable non-words) are remarkably similar, differing primarily in the amplitude of a late negativity peaking around 400 ms. This N400 component is a negative-

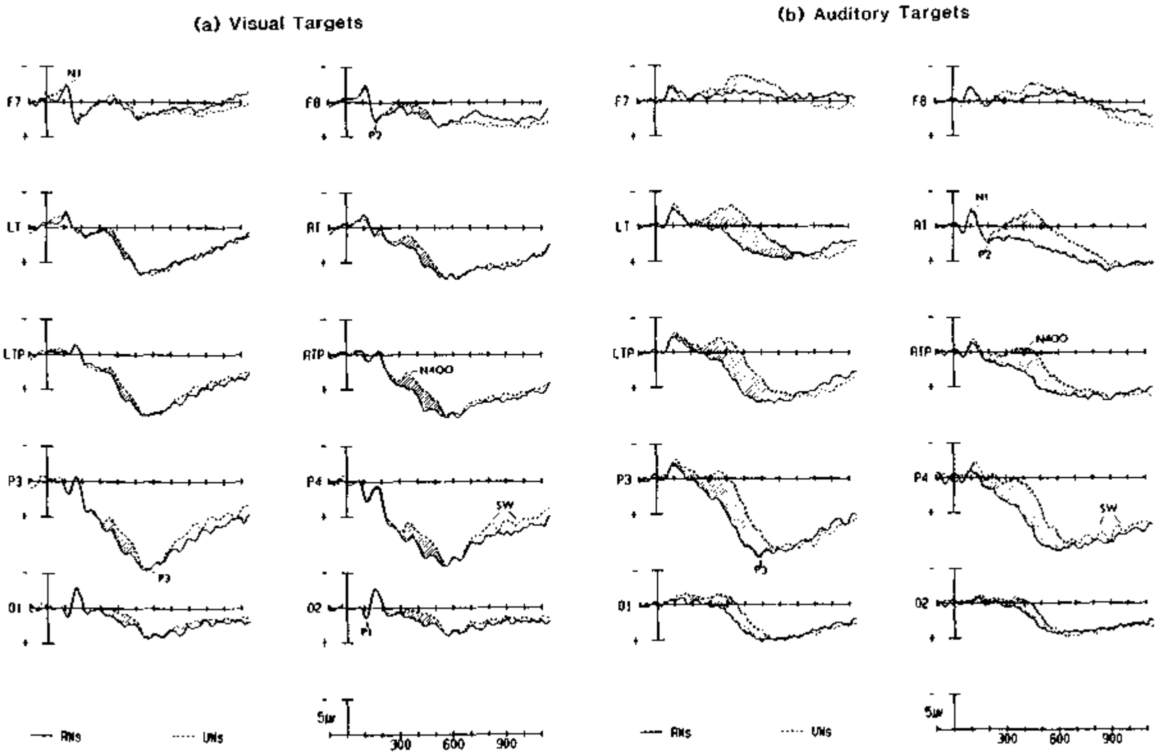

Fig. 1. Grand-average waveforms to semantically related (RW) and unrelated (UW) word targets for the visual (a) and the auditory (b) modalities. Stimulus onset is the vertical calibration bar. The diagonal hash lines represent the area of the N400 effect. Negativity is up in this and all subsequent figures (from Holcomb and Neville, 1990; reprinted by permission of Lawrence Erlbaum Associates Ltd., Hove, UK).

going wave between 300 and 600 ms post-stimulus; on average the N400 is broadly distributed across the scalp surface. Often, albeit not always, the N400 is slightly larger over the right than the left side of the head; this pattern of asymmetry is most pronounced for right-handed subjects with no left-handed family members. Right-handers with left-handed family members seem to show less or in some cases a reversed asymmetry in the 300–700 ms region of the ERPs to open class words (Kutas, Van Petten and Besson, 1988).[6] Moreover, the older the subjects, the later the onset and peak latencies of the N400. Note that its laterality and sensitivity to familial sinistrality have been most systematically studied for words presented in sentential contexts; it is likely that they will generalize to findings for words in isolation and other contexts, but this is not known with certainty. The N400 amplitude is usually larger for pseudowords than words whether they are written or spoken (Bentin, 1987, 1989; Rugg, 1987; Rugg and Nagy, 1987; Holcomb, Coffey and Neville, 1992). By contrast, the ERPs to true non-words are characterized by a large positivity in the same region where pseudowords and real words go negative. While the functional nature of the N400 is not yet fully known, the general pattern is highly reproducible and could therefore be quite revealing if it were different in patients with certain linguistic deficits.

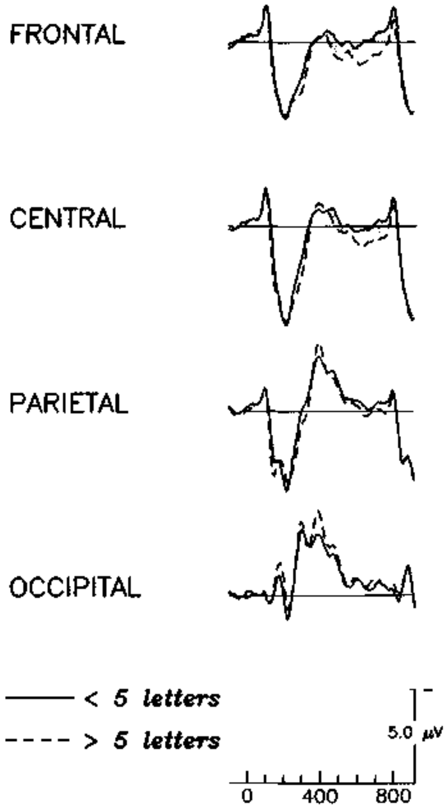

Fig. 2. Comparison of grand-average ($N = 16$) ERPs elicited by sentence intermediate content words comprised of less than five letters (solid line) versus those comprised of five letters or more. These ERPs were recorded in a sentence experiment, words presented one every 700 ms; task was to read sentences for meaning.

Among the relevant factors influencing the brain's electrophysiological responses are:

(1) *The length or number of letters in a written word.* This factor also influences the amount of time that people spend fixating or gazing at a word; approximately 25–30 ms per letter. In the ERPs this is seen in the amplitude of a relatively low-frequency (slow and long-lasting) positivity mostly at the frontal sites; the longer the word, especially after 5 letters, the larger the amplitude of this slow positivity (Van Petten and Kutas, 1990) (see Fig. 2).

(2) *The frequency of occurrence of a word in written or spoken language.* This too correlates with eye fixation/gaze duration times, 25–30 ms per unit log frequency. In the ERP, high-frequency words tend to have a smaller negativity between 300 and 600 ms (i.e. N400) than do low-frequency words (Van Petten and Kutas, 1990). The effect of this factor in the ERPs interacts with repetition (Rugg, 1990) and context (Van Petten and Kutas, 1990).

(3) *Concreteness of a word's referent.* Concreteness refers to the extent to which a word has a concrete, physical referent; it has been quantified by asking subjects to rate words along a concrete/abstract dimension.[7] With one exception (Smith and Halgren,

[6]It is likely that the N400 region of the ERPs to a word is comprised of several subcomponents. For the purposes of the present discussion we are describing the characteristics of the largest, most robust subcomponent.

[7]Although overlapping with ratings of imageability, concreteness and imageability refer to different word attributes.

1987), the ERPs elicited by concrete words are more negative between 300 and 600 ms post-word onset than the ERPs elicited by abstract words (Paller, Kutas, Shimamura et al., 1987; Kounios and Holcomb, 1994). This effect obtains regardless of whether concreteness is incidental or fundamental to the task requirements, although it is larger when attention is directed to the concreteness dimension (Holcomb, personal communication).

(4) *Function words versus content words.* With respect to our vocabulary, a general distinction is often made between words that bear meaning (nouns, verbs, most adjectives, -ly adverbs) and the 'little' words that help in the parsing of phrases and sentences (articles, conjunctions, prepositions, verb auxiliaries, etc.). The first category of words is referred to as content words or open class words; the second category is called function words or closed class words.

To date, there has been little work comparing ERPs to words that fall into different grammatical classes such as nouns versus verbs or adjectives versus adverbs or pronouns versus prepositions, etc. However, there have been several reports directly comparing ERPs to open class or content words with those elicited by closed class or function words, primarily when they occur in sentences (Kutas and Hillyard, 1983; Van Petten and Kutas, 1991; Neville, Mills and Lawson, 1992; Nobre, 1993). These comparisons have revealed a number of reliable differences between the ERPs to words in these two vocabulary types (see Fig. 3).

Among the differences are: (1) larger N1 and P2 components for open class words; (2) greater negativity (N280) between 200 and 500 ms for closed than open class words over anterior sites; this negativity is larger over the left than right frontal sites; (3) greater negativity (N400) between 200 and 500 ms for open than closed class words over central and posterior recording sites, especially over the right hemisphere; (4) greater negativity between 400 and 700 ms over frontal regions for closed than open class words.

To date, it is not clear which characteristics of the words that fall into these two vocabulary classes are responsible for the ERP differences. One view holds that several of these ERP differences (most notably the N280 and N400) reflect the hypothesized differences in the anatomical systems that subserve the storage and/or processing of content words and function words. An alternative interpretation holds that the difference between open and closed class words is continuous rather than dichotomous and that it is the role a word plays within a sentence rather than its surface

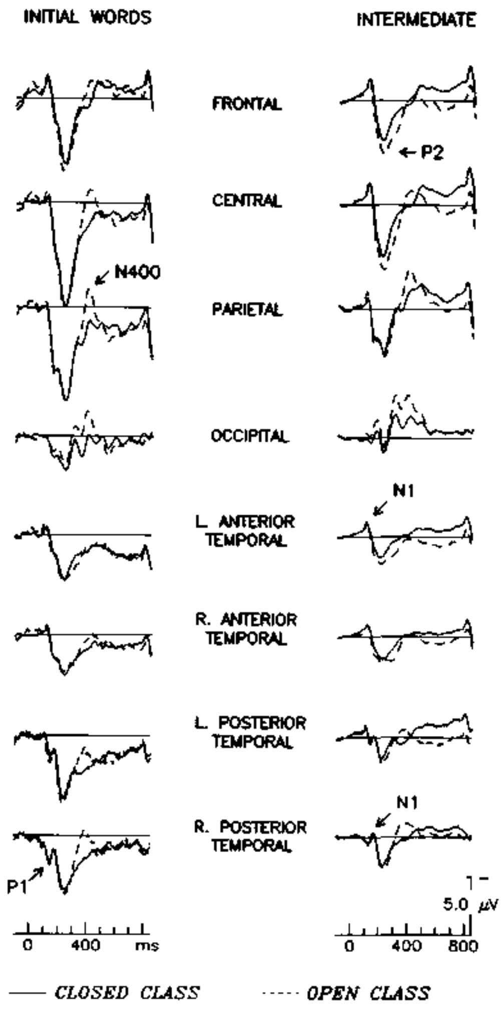

Fig. 3. Grand-average ($N = 16$) ERPs elicited by function (closed class) and content (open class) words in either sentence initial (left column) or sentence intermediate (right column) positions from four midline and two pairs of lateral sites each referenced to linked mastoids. These ERPs were recorded in a sentence experiment, words presented one every 700 ms; task was to read sentences for meaning.

form or locus in the brain that determines whether it behaves as an open or closed class word. On this view, the differences in the speed or accuracy of processing open versus closed class words can in large part (if not totally) be ascribed to factors which are correlated with lexical class membership but do not determine them such as word length, frequency of usage, repetition, contextual constraint, abstractness of meaning, referentiality. On average, closed class words tend to be shorter, higher frequency in overall usage, more often repeated, more predictable from context, and less imageable. As these characteristics are not orthogonal (e.g. high-frequency words tend to be shorter than low-frequency words), it has been difficult to tease apart the differential contributions of these factors to the open/closed class ERP differences. Nonetheless, Neville et al. (1992) argue for a fundamental distinction on the basis of median splits on some of these factors.

The processing consequences of this distinction between the lexical classes can be observed in Broca's aphasics who often have disproportionate difficulties in dealing with closed class items (cf. Marin, Saffran and Schwartz, 1976; Friederici and Schönle, 1980; Rosenberg, Zurif, Brownell et al., 1985). However, considerable disagreement exists as to which processing impairment accounts for the difficulties these patients have with closed class elements. For instance, some attribute the difficulties with closed class items to the loss of a special, fast access route for these items (Bradley, Garrett and Zurif, 1980). Others have claimed that processing impairments of closed class items derive from a phonological deficit (Kean, 1977), or from a selection of syntactic structures that have no slots for closed class items (Stemberger, 1984).

(5) *The number and nature of orthographic neighbors a word has.* Some words look like very few or no other words (e.g. 'circus', 'trout') while other words have a strong resemblance to many different words. By summing all of the potential words that can be generated by changing only one letter of a given word at a time, it is possible to estimate the size of the neighborhood of a word (i.e. *N*-metric). To date, most of the RT data have been collected for relatively short words, that is, 4- or 5-letter words. The number of orthographic neighbors that a letter string possesses has been shown to influence pronunciation times for words, rejection times for non-words and masked priming effects for words (Coltheart, Davelaar, Jonasson et al., 1977; Forster, 1987; Patterson and Coltheart, 1987). Holcomb and his colleagues (personal communication) have found that the amplitude of the negativity between 300 and 600 ms for a word is sensitive to the size of the word's neighborhood, being larger for 4-letter words with larger rather than smaller neighborhoods.

The above findings are based primarily on written words occurring in relative isolation, that is, in a list one word at a time. In the cases that have been examined, the lexical factors seem to have a similar effect on the ERPs elicited by spoken words, but there are not as much data available.

ERPs to words in the context of another word

When a word is presented in the company of one or more other words, then it is possible to study the effects of context. Both the size and the timing of context effects can be quite revealing of normal and abnormal language operations. For a single word context, there is an increased likelihood that the associated ERP waveform will to some extent reflect the presence of this context. In the visual modality, a single word context can be related to the target word in a number of different ways: (1) identity (repetition priming); (2) visual similarity (orthographic priming); (3) rhyming (phonological priming); (4) associative relation (associative priming); (5) semantic relation (semantic priming). Simply put, similarity between two words along any of these dimensions reduces the amplitude of the negativity between 300 and 600 ms in the ERPs to the second word of a pair. The size, duration and scalp distribution of the reduction is a function of the characteristics of the word, the nature of the relation, and the subject's task. For purposes of illustration, we describe the ERP patterns in response to associative and semantic relationships.

The ERPs to the second of a pair of words that are associatively or semantically related are characterized by a reduction in N400 amplitude relative to words that are unrelated (e.g. Bentin, McCarthy and Wood, 1985; Rugg, 1985, 1987; Boddy, 1986; Kutas and Hillyard, 1989; Holcomb and Neville, 1990; Holcomb and Neville, 1991). The magnitude of this reduction is a function of the strength of the relation between the two words, being greater the stronger the relation. Thus, the ERPs to the second word of antonymic pairs (e.g. 'up-down', 'in-out', 'hot-cold', 'good-bad') are characterized by a large positivity between 250 and 300 ms whereas the ERPs to the second word in word pairs belonging to a category (e.g. 'animal-dog', 'cat-horse', 'fruit-apple', 'canary-robin', etc.) show some negativity in the N400 region followed by a later positivity (see Fig. 4).

The amplitude of the N400 elicited by category members seems to be sensitive to typicality, being smaller for the more prototypic members of a category (e.g. 'bird-robin', 'fruit-apple', 'weapon-gun') than for atypical members (e.g. 'bird-penguin', 'fruit-melon', 'weapon-machete'). This semantic relatedness effect on N400-amplitude has been observed for both written and spoken words. For spoken words, the N400 effect appears to be earlier and more prolonged as well as symmetric or slightly larger over the left than the right hemisphere (e.g. Holcomb and Neville, 1990). In contrast, the visual effect is usually slightly larger over the right hemisphere. The N400 semantic relatedness effect has been observed in a number of different tasks

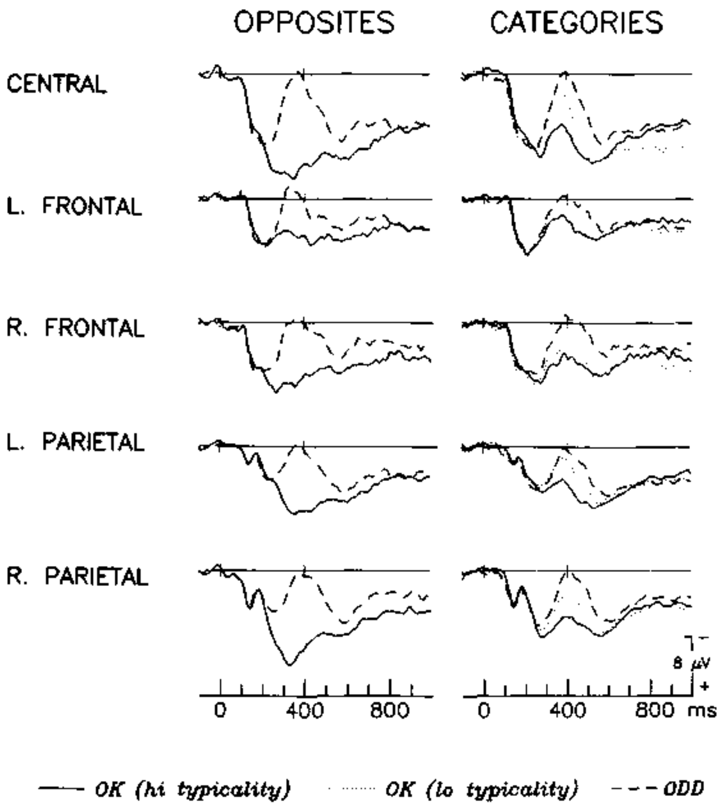

Fig. 4. Grand-average ERPs from 13 young students elicited by semantically congruous – OK (solid and dotted lines) and semantically anomalous – ODD (dashed line) words presented visually after a spoken phrase. The phrases were of two types: opposites (e.g. 'The opposite of black') or categories (e.g. 'A type of fruit'). For the categories, half the congruent words were prototypical category members (such as 'apple' for fruit, solid line) whereas the other half were less typical members (such as 'sword' for weapon, dotted line). Recordings are shown from midline central (Cz), left and right frontal (F7/8), and parietal (Wernicke's area and its right hemisphere homolog), each referenced to the average of the two mastoids.

including post-word letter search, lexical decision, memorize, count and semantic relatedness judgement. But also in the absence of an additional task, reliable N400 semantic relatedness effects have been obtained. The effect, although present in all cases, is largest when the judgement requires that the semantic relation between the words is noticed and attended (e.g. Bentin, 1987; Holcomb, 1988; Holcomb and Neville, 1990; Brown and Hagoort, 1993; Holcomb, 1993).

ERPs to words in sentence context

It is also possible to examine the response to a word in a larger context, such as a sentence. In this case, one can see the effects of semantic congruity or more generally semantic expectancy, and word position, and all the possible interactions between these factors and those that also influence the ERP to a word presented in isolation (e.g. frequency, concreteness). It was within the context of a sentence that Kutas and Hillyard (1980) first observed the presence of a large N400 component in response to semantic violations. The N400 elicited by an anomalous open class word occurring at different ordinal positions within a sentence peaks between 380 and 440 ms and is larger relative to a pre-stimulus baseline over posterior than over anterior regions of the scalp (Kutas and Hillyard, 1983). In the visual modality, the size of the N400 congruity effect has been found to diminish linearly with advancing age (Gunter, Jackson and Mulder, 1992; Kutas, Mitchiner and Iragui-Madoz, 1992).

For example, the ERPs to the word 'dog' in the sentence 'I take coffee with cream and dog.' would be characterized by a large N400 component. By contrast, the ERPs to the expected ending for this sentence, 'sugar'[8], would be characterized by a positive-going wave in the 300–600 ms region. An anomalous ending like 'sweetness' would also elicit an N400, but its amplitude would be somewhat smaller, presumably because 'sweetness' is semantically related to the expected ending 'sugar'. The results of several studies suggest that the ERPs to a congruent ending like

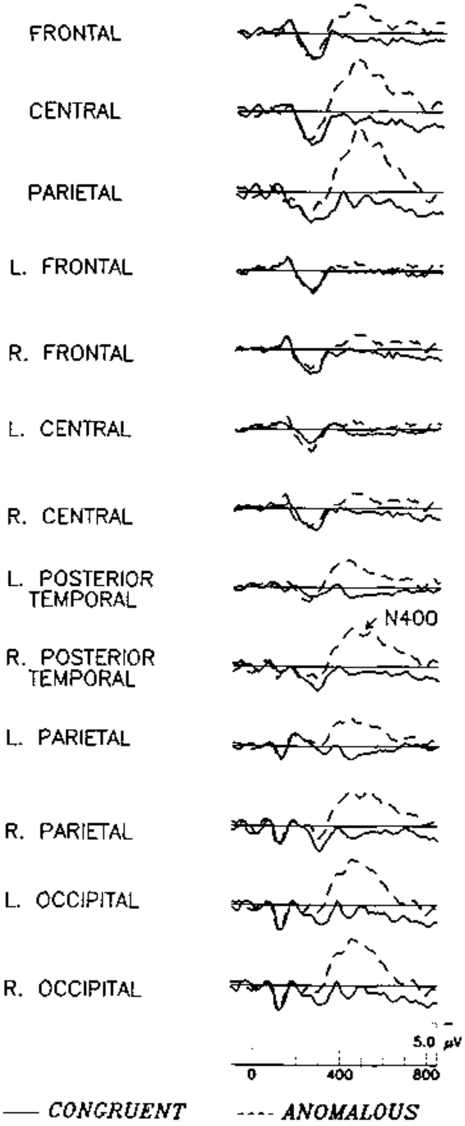

Fig. 5. Grand-average ERPs ($n = 9$) elicited by semantic anomalies (dashed line) and semantically congruent control words (solid line) embedded in stories presented one word at a time (approximately one every 500 ms). Subjects read text for comprehension tested via a multiple choice questionnaire. Recordings are from midline frontal (Fz), central (Cz), and parietal (Pz) sites and from 5 pairs of lateral electrodes from front to back of the head, including frontal (F7/8), central (over Brodmann's area 41), posterior temporal (T5/6), parietal (over Wernicke's area), and occipital (O1/2) referenced to the left mastoid (A1).

[8]The ending which would be given by over 90% of a group of subjects if they were asked to fill in the final word given a sentence fragment consisting of all but the final word. This measure of expectancy is called cloze probability. This sentence is thus an example of a highly constraining sentence leading to a highly likely ending which in turn has high cloze probability.

'milk' ('I take coffee with cream and milk.') would also be characterized by a negativity in the N400 region, but its amplitude would be smaller still. In short, the largest N400s are elicited by semantically anomalous words; anomalies related in meaning to words expected but not presented in a context have reduced N400s (Kutas, Lindamood and Hillyard, 1984; Holcomb and Neville, 1991).

The ERPs to open-class, congruous words can be negative or positive in the N400 region depending on a number of factors (Kutas and Hillyard, 1984). For congruent words, the amplitude of the N400 is a function of the word's expectancy (operationalized in terms of its cloze probability). For simple declarative sentences, a word's expectancy can also be crudely estimated by its ordinal position in the sentence. Under the assumption that words at the beginning of a sentence are normally less constrained (expected) than words near the end of a sentence, one might expect the N400 for words at the beginning of a sentence to be larger than those at the end of a sentence. This prediction was confirmed by Van Petten and Kutas (1991) who showed that the amplitude of the N400 to open class words is an inverse function of the word's ordinal position in the sentence. This reduction in N400 amplitude with ordinal position was not observed for open class words in so-called 'syntactic' sentences, that had the structural properties of formal English but no meaning (e.g. 'He ran the half white car even though he couldn't name the raise.'). Van Petten and Kutas (1991) also observed an interaction on N400 amplitude between word position, word frequency and sentence type. In 'syntactic' sentences, the N400 to low-frequency open class words was larger than that to high-frequency words regardless of position, while in simple congruent (i.e. semantically interpretable) sentences, this frequency effect was present only for words occurring early in the sentence.

Syntactic ERP effects

The ERP effects of various types of syntactic violations have been examined mainly within sentence materials. While ERP studies of syntactic processing are still relatively limited in number, on the whole the results suggest that the ERP responses to violations of syntactic preferences are different from the classical N400. At the same time, however, it seems that there is no single, unique ERP pattern that characterizes all 'syntactic' violations. Further research is needed to establish the basic classes of ERP responses to different aspects of syntactic processing.

Existing electrophysiological studies of sentence processing and parsing suggest two candidate ERP effects that appear to be related to syntactic analysis: (1) a large, broad, symmetric, positive-going shift that has been variously labelled the P600 or syntactic positive shift (SPS) and (2) an earlier left anteriorly-distributed negativity (LAN).

The SPS/P600 has been observed in response to a number of different types of syntactic violations in English and Dutch. For example, Hagoort, Brown and Groothusen (1993) compared ERPs to Dutch sentences that violated the agreement between the subject noun phrase and the finite verb (e.g. * 'The spoiled child throw the toys on the floor.') with those to their correct companion sentences ('The spoiled child throws the toys on the floor.'). They observed a positive shift starting about 500 ms post-stimulus onset in response to the finite verb in the grammatically incorrect version. This positive shift was followed by a negative shift for words further downstream in the ungrammatical sentences (see Fig. 6).

The same effect was also obtained following violations of normal word order within Dutch noun-phrases (e.g. 'the expensive very tulip'). Osterhout and Holcomb (1992), likewise, reported similar ERP effects to violations of verb subcategorization and phrase structure constraints in English. In one of their experiments subjects were asked to read active sentences wherein the finite verb was followed by a clausal complement (e.g. 'The broker hoped to sell the stock.'). In some cases, however, the sentences were ungrammatical because the verb required an NP-complement instead (e.g. * 'The broker persuaded to sell the stock.'). The infinitival marker 'to' in the ungrammatical sentences elicited a positive shift starting 400–500 ms after stimulus onset and lasting on the order of 400 ms. In an attempt to give a general functional characterization of the SPS/P600, it has been suggested that the

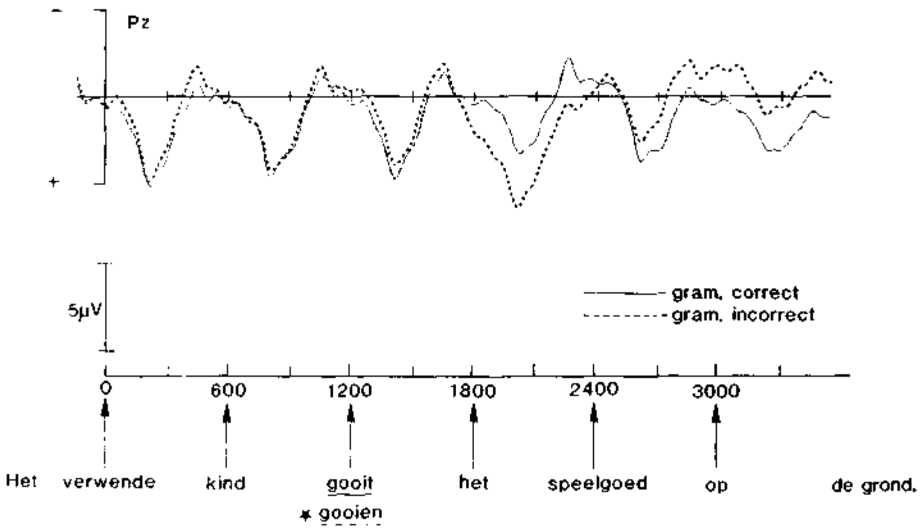

Fig. 6. Agreement violation. Grand-average ERPs ($n = 34$) for Pz, for the grammatically correct and incorrect critical words (CW). The CW renders the sentence ungrammatical in the incorrect version of the sentences. The CW is preceded by two and followed by three words. The translation of the example sentence is: 'The spoilt child throws/throw the toy on the ground' (the zero alignment point is on 'spoilt').

potential is elicited by any word in a sentence that renders the assignment of the preferred structure for the incoming string of words impossible (Hagoort et al., 1993; Hagoort and Brown, 1994). In most cases, the SPS has been maximal over parietal sites, and bilaterally symmetric; however, Osterhout and Holcomb (1992) found that the SPS was more posteriorly distributed for phrase structure violations than for subcategorization violations. Among the issues that remain open with respect to this effect are (1) what factors are responsible for the variation in scalp distribution and latency observed across studies and (2) how the SPS/P600 relates to the family of P300 components (Osterhout and Holcomb, 1992; Hagoort et al., 1993).

In several studies, violations of syntactic constraints have yielded a more complex pattern of effects, including left anterior negativities (LAN), especially large over frontal and anterior temporal sites of the left hemisphere. For example, frontal negativities (as well as a small P600) were observed to morphological violations resulting from a mismatch in number marking for adjective-noun pairs (e.g. 'six apple' instead of 'six apples') or to wrong tense marking (e.g. 'Ice begins to grew.' instead of 'Ice begins to grow.') (Kutas and Hillyard, 1983). Rösler, Pütz, Friederici et al. (1993) observed left anterior negativities in response to the final words of German sentences that did not fit their context for syntactic reasons (e.g. * 'The accused has dishonest.'). Neville, Nicol, Barss et al. (1991) observed left anterior-frontal negative effects for violations of phrase structure constraints, which were realized by changing the obligatory word order of the head noun and the preposition in a noun-phrase (e.g. * 'Ted's about films America.'). More complex patterns of results were observed to two other violation types in the Neville et al. study. LAN effects were also observed by Kluender and Kutas (1993) in sentences containing both direct (e.g. '*What* did you say you put __ on the table?') and indirect (e.g. 'Did you say *what* you put __ on the table?') *wh*-questions. The underlining in these examples indicates the position where the questioned *wh*-constituent logically belongs, referred to in the psycholinguistic literature as 'gap'. Kluender and Kutas observed a LAN effect whenever a questioned *wh*-constituent was separated from its gap, as in these examples. They concluded that this effect was related to holding the questioned *wh*-

constituent in working memory pending its assignment to the gapped position for purposes of syntactic and semantic interpretation.

In short, LAN effects have been observed with a variety of sentence types. They seem to be related to some aspect of processing necessary for syntactic analysis. Across the various studies, there are differences in both the onset latencies and topography of these LAN effects. Thus, at present it is difficult to know whether we are dealing with a single process, a family of related processes or several distinct processes. As the extent to which the LAN effects in these different studies are related is not yet clear, a unifying account of what leads to their elicitation must await further research. It will be especially important to determine what underlies the reported variations in the onset and distributional characteristics. What is clear, however, is that LAN effects are qualitatively different from the typical N400 effects seen following violations of semantic constraints.

For current purposes, the take-home message is that different linguistic violations have very different electrical signatures. Both SPS/P600 and LAN effects indicate that to a large extent the brain honors the linguistically motivated distinction between semantic and syntactic analyses. This fact can help in the design of studies on language deficits. Once a reliable 'syntactic' ERP pattern has been established and the essential features of the constraints being stretched or violated have been identified, the ERP can be used to test hypotheses about impairments in aspects of syntactic processing in patients with clinically observed syntactic deficits after a brain injury.

Methodological concerns

Both the reliability and interpretability of ERP data collected from brain-damaged and language-impaired individuals are a function of the extent to which certain methodological desiderata are met. On the practical side, there are the decisions regarding the appropriate length of a testing session, whether or not to apply eye movement (electro-oculogram or EOG) correction procedures and if so which one, the number of trials per condition, etc. (see Chapter 1, this volume). On the interpretive side are the decisions regarding the requisite control groups and control tasks for effectively reducing the space of potential explanations. We start with a discussion of these latter concerns.

When to interpret what and how?

Let us assume that we have recorded ERPs in a language task from a group of aphasic patients with comprehension deficits, documented via their performance on a clinical test battery such as the Boston Diagnostic Aphasia Examination (BDAE; Goodglass and Kaplan, 1972) or the Aachen Aphasia Test (AAT; Huber, Poeck, Weniger et al., 1983). Let us further assume that on average, the characteristics of the N400s elicited by certain linguistic input in this group are unarguably different from the 'normal' pattern. Prima facie it may seem reasonable to link this observable difference in the N400 directly to the comprehension deficit of the aphasics. However, there are certain methodological criteria that must be satisfied before such an interpretive link is justified:

(i) Appropriate control groups must be chosen. It is well documented that ERP components change across the lifespan (e.g. Poon, 1980). Thus, the standard staple of cognitive ERP experiments, namely the college undergraduate, cannot serve as the appropriate point of comparison for the patient data. At minimum, there must be a control group of neurologically unimpaired subjects who are matched to the patients on age, handedness, gender, and years of education.

However, even comparing aphasics' ERPs with those of a neurologically intact control group matched to the aphasics on all relevant dimensions does not license the conclusion that an abnormal N400 pattern is a direct index of the comprehension deficit in the aphasics. For one, this comparison does not rule out the possibility that the aphasic patients produced atypical N400s because they have sustained a brain injury rather than because of any language-specific deficit. A valid check of whether the ERP change is a non-specific sequela to brain damage or a specific marker of a language-processing deficit is to include a control group of brain-damaged patients without language problems. Clearly, if these patients show N400 effects similar to those of the aphasics, an interpretation of the 'abnormal' responses in terms of a specific language impairment is unwarranted.

(ii) The specificity of the differential ERP effect to aspects of the linguistic processing under investigation must be determined. To this end, it is useful to compare the ERP effects in one or more linguistic tasks to ERP effects in several non-linguistic, cognitive tasks (preferably of equivalent processing difficulty). If the pattern of effects for the language and non-language-related ERPs is very similar, then one should be hesitant to ascribe the ERP effects in the language task solely to the language deficit of this patient group. For instance, if aphasic patients showed a reduced P300 in response to targets in an auditory oddball task as well as a reduced N400 component to sentence-final semantic anomalies (cf. Kutas and Hillyard, 1980), then interpreting the N400 effect would be more difficult than if the P300s fell within normal bounds. The greater the number of cognitively related components that are abnormal across a number of different experimental settings, the greater the likelihood that changes in any one of them are probably a sign of an across-the-board deficit caused by brain insult. However, given the multidimensional nature of the ERP, some interpretive ambiguities may be mitigated by meticulous comparisons of the scalp distributions of the different ERP effects. To the extent that the topographical profiles of the ERP effects in the different conditions are distinguishable, the chances of a viable explanation of each in terms of specific rather than general cognitive deficits are increased, albeit still being difficult to achieve.

Another likely pattern of results that is quite difficult to interpret is a change in a language-related ERP effect occurring together with a change in some but not all non-linguistic, cognitive ERPs. This pattern might indicate that the language impairment is a by-product of a general cognitive deficit, which explains the language impairment and other cognitive problems; but then again it might not. Since lesions are to a large extent an artifact of the vascularization pattern of the brain (Poeck, 1983), even reproducible associations between 'abnormal' ERP effects in language and non-language tasks does not in and of itself guarantee a principled relation between the underlying cognitive architectures. At best, this scenario provides circumstantial evidence for a potentially informative relation between language function X and a non-language, cognitive function Y, which then could be the basis of a hypothesis for further experimentation.

(iii) Experiments with aphasic patients must be designed so that a change in a language-related ERP effect will in fact be informative about the locus of the impairment within the cognitive architecture of language processing. That is, it is generally most revealing to test hypotheses that make very precise predictions about differential patterns of ERP activity across different language tasks. For instance, if the comprehension deficit in a group of aphasic patients is presumed to be due to a malfunction in the mechanism that assigns syntactic structure to an incoming string of words rather than to a semantic deficit, then it is reasonable to predict an abnormal pattern of ERPs related to syntactic analysis (such as the SPS/P600) in the face of a normal pattern of ERP effects for semantic analysis (e.g. N400). Tyler (1992) proposed that creating an on-line processing profile for each patient experiencing difficulties with a particular language function provides a reliable means for determining the level of the dysfunction (i.e. lexical access, semantic integration, syntactic analysis); this in turn presumably provides a strong foundation for a detailed account of the functional locus of dysfunction. One way to accomplish this is to conduct a series of ERP experiments, each of which is designed to tap a different aspect of the cognitive architecture for a particular language function. The resulting patterns of amplitudes, latencies and/or topographical profiles interpreted in light of the stimuli and processes that engendered them would undoubtedly help in forging a well-specified functional account of the particular language impairment under investigation.

In summary, we believe that electrophysiological investigations with patients should be motivated by neurolinguistic issues, employ several control groups, and include recordings from some non-language, cognitive tasks to complement the results of the language task(s). Furthermore, we suggest that a truly detailed account of the language impairment presupposes that for each patient one has in hand a language processing profile, which can serve to uncover the linguistic level at which impairment is most likely to surface during on-line language processing. Although the above methodological concerns were specified only for aphasic patients with comprehension deficits, it goes without saying that mutatis mutandis the same logic for reducing the interpretation space applies to other groups of patients with language impairments, including developmental dyslexics, Alzheimer patients, schizophrenics, etc. In addition, exactly the same methodological concerns hold for other measures of brain activity, such as MEG, PET and functional MRI.

Finally, although it may not always be possible to implement all of the above requirements in practice, it is nonetheless important to remain mindful of the consequences that various compromises will have for interpreting data from language-impaired subjects.

What one has to think about in testing patients

In addition to methodological concerns that have direct relevance to the interpretation of the data, there are a number of mundane, practical issues that must be considered when testing brain-damaged patients with a language impairment. A discussion of the more relevant practical concerns follows:

(i) *Eye movements.* Subjects in ERP experiments are routinely asked to refrain from unnecessary blinking and from making other eye movements during the recording epochs. On the whole, the average undergraduate can comply easily or be tossed if they do not. By contrast, many elderly subjects and brain-damaged patients find it extremely difficult to coordinate the primary task with the secondary task of keeping their eyes steady. In our experience, it is best not to dwell on excessive eye movement problems but rather correct the data off-line with one of the available adaptive filter algorithms (cf. Gratton, Coles and Donchin, 1983; Kenemans, Molenaar, Verbaten et al., 1991). These electro-oculogram (EOG) correction algorithms are designed to compute the EOG contribution to the electroencephalogram at different EEG-leads and to remove them prior to averaging.

(ii) *The dual task.* As previously mentioned, one of the strengths of the ERP technique is that reliable ERP effects can be obtained without requiring subjects to perform any task beyond reading or listening. While such additional tasks always create a dual-task situation wherein the subjects' task may interfere with the language processing operations under study, this is exacerbated in the case of brain-damaged patients faced with tasks such as lexical decision, word monitoring, etc. To exert greater control over the degree to which subjects attend to the input, it is possible to ask them questions following filler items, occasionally following experimentally critical items, or in a recognition test after all the materials have been presented.

(iii) *The test session.* Although test sessions of 3–4 h are not atypical in psycholinguistic ERP research, in general neither the physical nor mental condition of most patients allows for such long test sessions. In our experience, patient test sessions should not exceed 1.5 h including electrode placement and removal. In addition, we have found that the data are cleaner and more reliable when the test session is broken into smaller (10–15 min) epochs interspersed with short breaks; these breaks serve to keep the patient focussed on processing the language materials.

Testing patients also requires a sensitivity to their general condition. For instance, many patients are stressed when the recordings are made in a closed room without an accompanying person. As patients often prefer to be tested in the presence of their partner, it is worth considering ways in which the partners can be used without disrupting the required rigor of the experimental situation. Whenever possible, someone should sit by the patient during the session. In addition, the laboratory should be constructed so that patients with hemiplegia, which often accompanies aphasic symptoms, can be tested comfortably. In summary, in order to collect clean ERP data, it is helpful to be sensitive to the physical and mental conditions of the patient, and to adapt the testing environment to their needs.

Single-case ERP studies

Finally, we would like to point out some practical concerns in conducting single-case studies as compared to patient-group studies with the ERP technique. Over the last decade, the neuropsychological community has witnessed at times vehement debates on the scientific merits of patient-group studies. Those who believe that inferences about the cognitive architecture of an intact cognitive system based on the (mal)functioning of the impaired system can only be drawn from single-case studies gainsay the merits of group studies (e.g. Morton and Patterson, 1980; Caramazza, 1984, 1986, 1988; Badecker and Caramazza, 1985, 1986; Caramazza and McCloskey, 1988; McCloskey and Caramazza, 1988; Caramazza and Badecker, 1989). Counter to this inflexible position, some researchers have defended the value of both single case and patient-groups studies in neuropsychology but have pointed to limitations inherent in the single-case approach (e.g. Caplan, 1986, 1988; Shallice, 1988; Zurif, Gardner and Brownell, 1989; Bates, Appelbaum and Allard, 1991). This is clearly not the place to expound on the pros and cons of patient-group studies; however, we would be remiss not to mention that it is considerably more difficult to collect reliable and interpretable ERP data from a single patient than from a group of patients. As most neurolinguistic research is hampered from the outset by the limited availability of patients as well as by small, circumscribed sets of adequate linguistic materials, it is highly unlikely that enough ERP data can be recorded from any one subject to overcome the signal-to-noise problem and interpret the data unambiguously. In this respect ERPs are no different from most on-line RT measures or from MEG, PET, and functional MRI.

In chronometric investigations of lexical access or parsing, there are invariably individual subjects who do not pattern with the group means in some experimental conditions. Indeed, if this were not the case, there would be no need for statistical inference. Typically, this individual variation is treated as random and theoretically uninteresting noise, perhaps a sign of waning attention or fatigue. Group studies are presumed to magnify small, but theoretically interesting effects and to reduce contamination by experimental noise (Caplan, 1988). In this respect the situation (and underlying assumptions) are no different for language-impaired patients than for intact subjects. In sum, while there is no principled argument as to why single-case ERP studies with language-impaired patients should not be conducted, there are very practical reasons for not doing so, the temptation notwithstanding. With few (if any) exceptions, the small magnitude of the effects and the noise in the measurement render single-case analyses too unreliable for RT and ERP studies on language processing, alike.

ERPs and aphasia

Despite the potential value of using ERPs to define the functional nature of language comprehension deficits in aphasic patients, surprisingly little electrophysiological research has been conducted with this aim. Instead, the majority of ERP studies with aphasic patients have focussed on (1) the extent to which language processing in aphasics is mediated or controlled by the non-language dominant, right hemisphere (cf. Kinsbourne, 1971) and (2) whether or not patients with posterior lesions have subtle disorders of phonetic perception, the evidence that this deficit cannot account for the comprehension deficits in aphasic patients notwithstanding (cf. Blumstein, 1987, 1990).

By and large, the bulk of ERP studies of aphasia have sought support for the hypothesis that functional recovery in linguistic processing in the aphasic patient is subserved by increased involvement of the right hemisphere, perhaps due to disinhibition from the damaged left hemisphere (Papanicolaou, Levin and Eisenberg, 1984; Papanicolaou, Moore, Levin et al., 1987; Papanicolaou, Moore, Deutsch et al., 1988; Selinger, Prescott and Shucard, 1989). This means that the right hemisphere is presumed to take over a process previously controlled by the language processing systems of the two hemispheres working in concert, or that some new system is formed in the right hemisphere, or that some existing system in the right hemisphere now modifies or adds to its function(s) to subserve certain language processes.

ERP probe paradigm

Many electrophysiological studies on aphasia have employed an ERP 'probe' paradigm (cf. Shucard, Shucard and Thomas, 1977; Papanicolaou, 1980). In this paradigm evoked potentials to simple, task-irrelevant (i.e. 'probe') stimuli are recorded while subjects engage in a number of different modes of cognitive processing. Subsequently the ERPs to the probe stimuli (e.g. a tone or a flash of light) in an attend control condition are contrasted with the variations in the ERPs to the task-irrelevant probe and serve as a basis for inferences about the differential task-specific activation of different neuronal systems in the two hemispheres. The basic assumption behind this approach is that '...processing information required by the task will compromise the efficiency of neuronal systems in processing a concurrent irrelevant probe stimulus...' Moreover, '... that the degree of efficiency loss would most likely covary with the complexity, therefore the "computational" requirements of the task.' (Papanicolaou and Johnstone, 1984, p. 108). In other words, the technique is based on the assumption that the neural tissue carrying out a particular cognitive task (e.g. perception of words or music) contributes less to the generation and/or modulation of the ERP components evoked by irrelevant probe stimuli when it is actively engaged by an ongoing task than when it is not so engaged (Shucard et al., 1977; Papanicolaou et al., 1984). The exact mechanism by which hemispheric engagement modulates the probe ERPs remains un(der)specified.

In a series of studies, Papanicolaou and his colleagues employed variants of the ERP probe paradigm to compare language processing in recovered aphasic patients with non-aphasic patients with diffuse (Papanicolaou et al., 1984) or right hemisphere brain lesions (Papanicoulaou et al., 1987, 1988), and with age-matched control subjects. In these studies, subjects were exposed to sets of low-imagery, high-frequency nouns presented once every half second; their task was to memorize these words for either subsequent recognition or recall. The ERPs to task-irrelevant probes (e.g. clicks or tones) in this condition were compared to those elicited by the same probe stimuli when subjects actively attended the probes. ERPs were recorded over left and right temporal sites (T3 and T4). The primary measure was the ratio of the amplitudes of the peak-to-peak difference between the N1 and P2 components of the probe ERPs in the language and in the attend probe control conditions. The resulting ratios were used to estimate the attenuation for the probe-ERPs in each of the hemispheres. In all cases, the aphasic patients differed from the other subject groups in showing attenuated ERPs over the right instead of the left hemisphere. Papanicolaou et al. (1988) found a similar pattern of results for language tasks involving monitoring lists of words for specific consonant clusters or specific semantic categories. The results were interpreted as evidence for a shift in the dominance of language processing from the left to the right hemisphere in aphasic patients. The authors further suggested that this shift may be the mechanism underlying recovery of language functions lost after left hemisphere injury. Selinger et al. (1989), likewise, obtained similar results from aphasic patients monitoring for a word in a spoken prose passage, a melody in pieces of classical music, and a click embedded in white noise. In all three conditions, the ERPs of interest were evoked by randomly occurring, irrelevant tone pairs. Whereas the normal controls did not exhibit any significant task-dependent asymmetries, the aphasic group showed asymmetric P2 and N2 components but only during the verbal task. The authors concluded that since the verbal task was more demanding for the aphasic than for the control subjects and the right hemisphere was released from the inhibitory control of the now damaged left hemisphere, the right hemisphere took a more active role in language processing. On this view, the nature of the errors that aphasics make may reflect the possibility that the right hemisphere is less well equipped for language processing than the left hemisphere.

ERPs related to language stimuli in aphasics

ERP researchers also examined the hypothesis that patients with left posterior lesions have an impairment in phonetic perception. For instance, Aaltonen, Tuomainen, Laine et al. (1993) described two patients with left posterior lesions who generated a mismatch negativity (MMN) to tones, but not to vowel sounds. Näätänen and his colleagues have proposed that the MMN is a task-independent, automatic consequence of basic sensory analyses processes, which is elicited by any stimulus that deviates from one or more of the physical stimulus parameters of a repetitively occurring series of identical 'standard' stimuli (for review, see Näätänen, 1990). In the Aaltonen et al. study, four aphasic patients with left hemisphere lesions were exposed to an oddball paradigm with two conditions. In one, occasional 1260 Hz tones were interspersed with frequently occurring 1002 Hz tones, while in the other synthetically produced vowel /i/ sounds occurred infrequently within a series of two other synthetically produced vowels chosen from the Finnish /i/-/y/ continuum. Of the two patients with frontal damage and the two with posterior damage, one of each type had clear auditory language comprehension deficits, while the remaining two exhibited almost normal comprehension according to the Finnish version of the Boston Diagnostic Aphasia Examination (BDAE). All four patients generated a MMN to deviant tone stimuli. By contrast, only the anterior patients showed an MMN to the deviant vowel. The apparently selective absence of an MMN to synthetic vowels after left temporoparietal damage led the authors to hypothesize that posterior regions of the left hemisphere may house the memory traces for vowels. However, the authors admitted that the data were consistent with the possibility that the left temporal region is required for the generation of an MMN to complex as opposed to simple acoustic stimuli. Interesting as these results are, it is unclear how they relate to the language comprehension deficits of these patients, as the authors readily acknowledged. The presence or absence of an MMN to synthetic vowels does coincide with lesion site; however, it is orthogonal to whether or not the patient had an auditory language comprehension deficit according to the BDAE.

A similar problem plagues interpretation of a study by Praamstra, Stegeman, Kooijman et al. (1993), who recorded long latency auditory evoked potentials to 1 kHz tone bursts from a group of 20 aphasic patients with predominantly left posterior lesions. Despite substantial variability among the patients, the pattern of results suggested a greater asymmetry in patients with more severe comprehension deficits. But, given that the patients did not differ in their comprehension of speech, written words or sentences, the functional significance of this result is unclear. It also remains to be explained how a deficit specific to auditory processing could lead to a central, supramodal language comprehension deficit.

In summary, none of the above studies used ERPs to elucidate the functional nature of language comprehension impairments in aphasia. Only recently have investigators begun to use ERPs to determine the extent to which various aspects of language comprehension (e.g. lexical access, lexical integration) are impaired in different types of aphasia.

One example of this neurolinguistically motivated approach is an N400-study aimed at testing recent claims about lexical-semantic processing deficits in Broca's aphasics (Hagoort, Brown and Swaab, 1991; Swaab, Brown and Hagoort, 1991). This ERP study was inspired by recent findings in a number of word priming studies with aphasic patients (Milberg and Blumstein, 1981; Blumstein et al., 1982; Milberg et al., 1987; Katz, 1988; Chenery, Ingram and Murdoch, 1990; Hagoort, 1993). These word priming data were gathered in speeded lexical decision tasks, wherein subjects were required to rapidly decide whether or not a sequence of letters or sounds was a legal word in the language. The decision time to a target word is typically speeded if the immediately preceding word is semantically related to it (Meyer and Schvaneveldt, 1971). This is referred to as the semantic priming effect. When aphasic patients and control subjects have been presented with visual or auditory prime-target pairs, or triplets (Milberg et al., 1987; Hagoort, 1993), comprised of words that were either related or unrelated in meaning, Wernicke's aphasics have consistently shown reliable semantic priming effects. These studies therefore have cast serious doubt on the classical view that it is predominantly Wernicke's aphasics who show a deficit in activating the semantic information associated with lexical items (e.g. Zurif, Caramazza, Myerson et al., 1974; Goodglass and Baker, 1976).

Surprisingly, Broca's aphasics have exhibited a much less stable pattern of performance, sometimes showing the expected priming effect (Blumstein et al., 1982; Katz, 1988) and other times showing no priming (Milberg and Blumstein, 1981; Milberg et al., 1987). The absence of a stable semantic priming effect in Broca's aphasics has led to the claim that these patients might be impaired in the automatic, rapid access to lexical-semantic information (Milberg et al., 1987). However, a recent priming study by one of the current authors yielded results that are difficult to reconcile with an impairment in automatic lexical-semantic processing (Hagoort, 1993).

To test further the integrity of lexical-semantic processing in Broca's aphasics, an ERP study was performed in which Broca's aphasics, elderly neurologically unimpaired controls, and non-aphasic patients with a right hemisphere lesion were asked to listen to 166 spoken word pairs. No additional task requirements were imposed on the subjects. Half of the word pairs were semantically related (e.g. BREAD – BUTTER), while the other half were unrelated in meaning. Prior to participating in the ERP experiment, all aphasic patients were screened with the Aachen Aphasia Test battery (AAT) and found to have light-to-moderate comprehension deficits.

Figure 7 shows the grand average ERPs at midline central site (Cz) for twelve control subjects matched in age and education with twelve Broca's aphasics.

For both subject groups, the semantically unrelated targets elicited larger N400s than did the related targets. Neither the onset nor the size of the N400 effects differed between the subject groups. Although the N1 in the aphasic patients seems to be reduced in amplitude compared to that in the normal controls, this difference failed to reach significance. In conclusion, like the normal controls, Broca's aphasics show an N400 amplitude reduction to the second word of a semantically related word pair. It seems reasonable to assume that the presence of an N400 effect presupposes that subjects accessed the lexical-semantic information associated with the auditory word forms. Since the patients' N400 characteristics did not deviate from those of the normal controls, there is no reason to assume that the patients accessed lexical-semantic information any differently from that of the normal subjects. The results of this study therefore suggest that the comprehension deficits in this group of Broca's aphasic is unlikely to be due to an impairment in rapid access to lexical-semantic information.

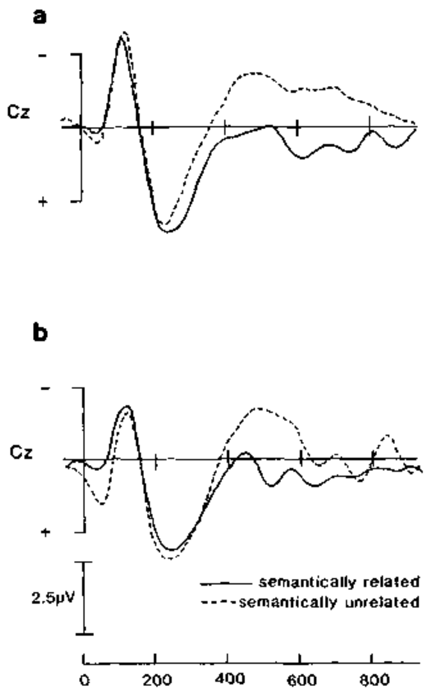

Fig. 7. Grand-average ERPs from (a) 12 normal elderly controls and (b) 12 Broca's aphasics, elicited to words preceded by a semantically related word (solid line) and to words preceded by a semantically unrelated word (dashed line). Stimulus onset is the vertical calibration bar. Words were presented auditorily. Each condition had 83 word pairs. Recording is from Cz referenced to the left mastoid.

In a second study, the same patients were asked to listen to spoken sentences that ended in a semantically congruous or anomalous manner. The Broca's aphasics showed a large N400 to sentence-final semantic anomalies; however, in this case, the size of the N400-effect was reduced and its onset was delayed (about 50 ms) relative to the N400-effect in normal controls. This pattern of results suggests that Broca's aphasics are impaired in their ability to integrate lexical-semantic information into a representation of the overall context (Hagoort, 1990; Hagoort et al., 1993).

These studies illustrate that it is feasible to apply the ERP method in neurolinguistically motivated ways to investigate language processing deficits in aphasic patients.

ERPs and developmental dyslexia

A primary problem in learning to read is the problem of creating a transparent interface between orthographic input and phonological structure (cf. Shankweiler and Crain, 1986). Hence, it is no surprise that reading skills do not develop normally if the metaphonological skills that are required to segment words into their constituent phonemes do not develop normally (Vellutino, 1979). However, it is unlikely that all reading problems are due solely to this factor. Among the prime candidates that have been proposed are deficits in syntactic processing (Byrne, 1981), limitations in working memory capacity (Shankweiler and Crain, 1986), and impairments in the time course of the processing of the rapid, transient characteristics of auditory and visual input (Lovegrove, Martin and Slaghuis, 1986; Tallal, Sainburg and Jernigan, 1991).

Somewhat surprisingly, few ERP studies of dyslexia have been aimed at testing any of these proposals. Instead, much like the electrophysiological work in aphasia, the emphasis has been on the idea that developmental dyslexia might be due to a shift in the hemispheric control of processes critical in reading; most of this work also has employed the probe technique (e.g. Johnstone, Galin, Fein et al., 1984; Shucard, Cummins and McGee, 1984). On the whole, the results of these probe studies reveal some ERP difference between normal and dyslexic readers, but these effects are neither predictable nor consistent across studies. The bulk of the remaining studies have merely documented the different patterns of ERPs in those with and without reading problems in a number of 'cognitive' tasks without reference to any particular hypothesis.

Different patterns of ERP asymmetries in normal and dyslexic readers have been obtained during different language tasks and in response to task-related stimuli. For example, Landwehrmeyer, Gerling and Wallesch (1990) recorded very slow potential (direct current (DC) recordings) while subjects read, detected orthographic errors, or generated antonyms in response to spoken words. In all cases, dyslexics were characterized by larger negativity over the right than left hemisphere whereas normal readers showed the reverse pattern. Other studies, however, have failed to find hemispheric differences in the ERPs of normal and dyslexic readers (e.g. Taylor and Keenan, 1990). Similarly, Galin, Herron, Johnstone et al. (1988) found that both the magnitude and scalp distribution of the EEG in the alpha (8–12 Hz) band recorded during spontaneous speech were the same for dyslexic and normal readers. In conclusion, the evidence in favor of an anomalous pattern of hemispheric lateralization for language processing in dyslexic readers is at best mixed. Before accepting the implications of this conclusion, let us examine the validity of some of the assumptions underlying the design of these studies. Since language is not a unitary function, it may be unreasonable to expect that the patterns of lateralization for very different language functions (e.g. speaking versus detection of orthographic errors) need be similarly disrupted in dyslexia. It should go without saying that it is essential that the choice of linguistic tasks be motivated by the nature of the presumed deficit. Similarly, the assumption that the entire left or the right hemisphere acts as a single unit in comprehending or producing language is clearly naive (cf. Wood, Flowers, Buchsbaum et al., 1991). Thus, it is unlikely that one pair of lateral electrodes will provide adequate coverage for assessing hemispheric asymmetries.

The results of a large number of studies comparing the ERPs to simple light flashes or tones of dyslexics with those of normal readers are similarly inconsistent. Some researchers have noted distributional changes in the ERPs to these simple stimuli (e.g. Preston, Guthrie, Kirsch et al., 1977; Sobotka and May, 1977; Chayo-Dichy, Ostrosky-Solís, Meneses et al., 1990); others, however, did not detect any differences (e.g. Weber and Omenn, 1977; Yingling, Galin, Fein et al., 1986). It is difficult to determine how seriously to take these inconsistencies given that none of these studies related the ERPs to normal or abnormal reading processes.

The results contrasting dyslexics with normal readers for longer latency, cognitive components have been somewhat more coherent. Most of these have focussed on the ERPs elicited by stimuli requiring some sort of classification; these ERPs are characterized by a late positive complex consisting of N2, P300 and SW components. Both the N2 and P300 have been shown to vary systematically in latency as a function of the complexity of the processes necessary for classification. A number of investigators have found that dyslexics and normal readers differ in the amplitude and/or latency of the P300 to nonverbal and verbal stimuli (Holcomb, Ackerman and Dykman, 1985, 1986; Harter, Anllo-Vento, Wood et al., 1988; Taylor and Keenan, 1990). For example, Taylor and Keenan (1990) found that dyslexics with a visual processing deficit had longer latency P300s to nonlinguistic symbols, letters and words in an oddball task. The dyslexics also had longer N2 latencies for symbols and words but not letters, presumably because the letters were too familiar.

Recently, Neville, Coffey, Holcomb et al. (1993) tested language impaired, reading disabled children (LI/RD) in a number of paradigms, including the detection of auditory and visual target events presented at different rates and in different spatial locations. They found that a subset of the learning impaired children who performed poorly on a rapid sequencing test had N1 components that had delayed latencies and reduced amplitudes in response to auditory stimuli, relative to the other LI children. All the LI children showed delayed N2 components and significantly smaller P1 and P300 amplitudes in response to visual stimuli (Neville et al. refer to these components as N230, P150 and P350, respectively).

In the same study, the subjects were required to indicate whether sentences presented one word at a time at a rate of one word per second did or did not make sense. The LI children generated larger N400s to all open class words as well as to sentence-final semantic anomalies than the control group. This was taken by Neville et al. to indicate a greater reliance on context for comprehension in the LI children. In addition, the LI children had an abnormal pattern of asymmetries for closed class words, that was most pronounced for the children who scored poorly on a test of syntax. In contrast to the left anterior asymmetry for closed class words in the control children, these children showed larger ERP responses over the right frontal areas.

Taken together, these findings underline the importance of distinguishing among subtypes of dyslexia (see also Fried, Tanguay, Boder et al., 1981; Bakker and Vinke, 1985; Castles and Coltheart, 1993). They further demonstrate that LI/RD children can have impairments in auditory and visual sensory processing as well as in more central aspects of language processing such as the processing of grammatical information. Thus, a dyslexic's performance on any language task may be a complex function of deficits in a variety of processes at different levels of analysis.

As space does not permit us to review all of the published ERP work on developmental reading disorders, we have given some representative examples of different approaches (for further studies, see e.g. Duffy, Denckla, Bartels et al., 1980; Mecacci, Sechi and Levi, 1983; Ollo and Squires, 1986; Stelmack, Saxe, Noldy-Cullum et al., 1988; Stelmack and Miles, 1990). The results of these studies, however, show a substantial degree of variability and inconsistencies. We believe that this is in large part due to a lack of precision in the assumptions concerning the relation between the deficit and the experimental tasks being used and a lack of appreciation for the different subtypes of dyslexia. Once these assumptions are winnowed and the existence of different subtypes is appreciated, ERPs can provide critical evidence on the nature of the underlying language processing deficits.

ERPs and SDAT

Language disturbances characterize a variety of neurological disorders besides the classical aphasias. For instance, Alzheimer (1907) noted a language disorder (paraphasic disturbances) in his original descriptions of senile dementia, although until recently the accompanying memory deficit has had more play. Insofar as the language capabilities of individuals suffering from some form of dementia have been investigated, the analyses have been restricted in scope to lexical functions; semantic, syntactic and pragmatic factors have received short shrift. The paucity of electrophysiological studies of language processing at any level in SDAT patients is even more apparent. With but few exceptions, electrophysiological investigations of dementia have focussed on the diagnostic utility of ERPs. As there is no definitive test of Alzheimer's in the living patient (short of a brain biopsy), it is frequently a difficult decision, especially in its early phases. This difficulty is exacerbated by the similarity of SDAT symptoms (e.g. memory impairment, speed of information processing, concentration) to those of pseudodementia due to depression. Since 1978, when Goodin, Squires and Starr reported that the latency of the P300 in a two-tone discrimination (oddball task) was delayed by two or more standard deviations from age-matched normal controls, substantial resources have been devoted to determining the utility of the P300 in diagnosing dementia in its early phases (Blackwood, St. Clair, Blackburn et al., 1987; Patterson, Michalewski and Starr, 1988; Kraiuhin, Gordon, Coyle et al., 1990; Williams, Jones, Briscoe et al., 1991). While it is unlikely that changes in language-related ERPs would have diagnostic specificity for SDAT, they might provide important information about the nature of language deficits in demented individuals.

As one characteristic complaint of SDAT patients is that they experience great difficulty in finding just

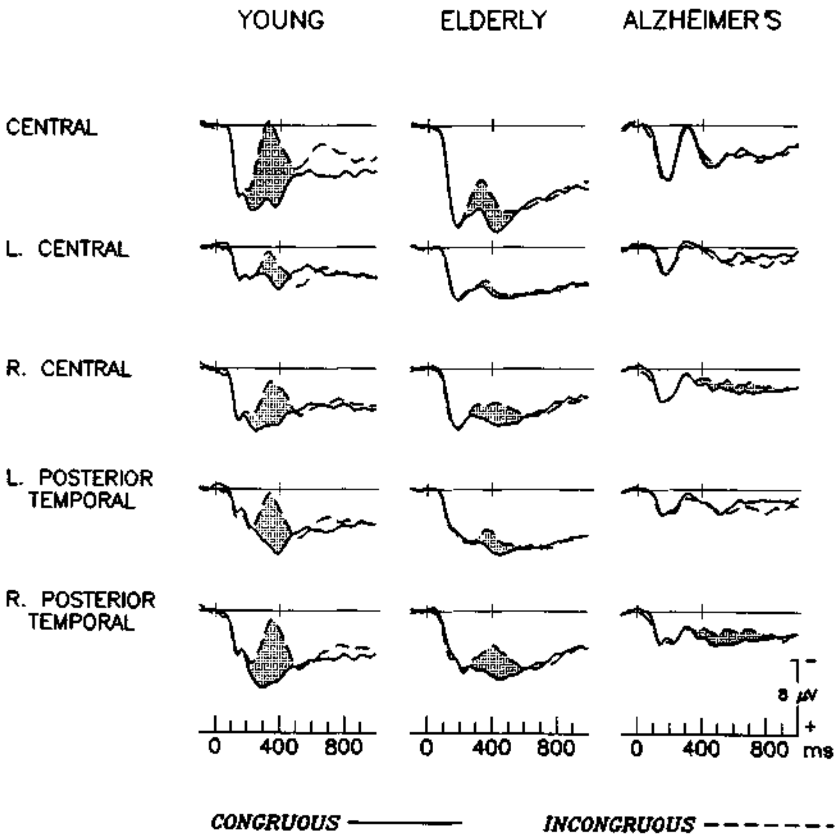

Fig. 8. Grand-average ERPs from 12 young students, 12 normal elderly controls, and 12 patients diagnosed with senile dementia of the Alzheimer's type, elicited by semantically congruous (solid line) and semantically anomalous (dashed line) words presented visually after a spoken phrase (e.g. 'The opposite of black').

the right word for a situation (i.e. anomia) or an object (i.e. confrontational naming) and it has been hypothesized that this naming disorder is due to an impairment in lexical semantics (i.e. SDAT patients have degraded semantic representations for some concepts), we decided to conduct a preliminary study to examine this suggestion. We chose to measure the N400 component of the ERP, given its sensitivity to semantic processing and to categorical relations (e.g. membership, typicality).

Thus, in a preliminary study conducted in collaboration with a neurologist, Vincente Iragui-Madoz, we presented a group of SDAT patients, age matched controls, and a group of undergraduates with a short phrase (e.g. 'A type of animal' or 'The opposite of black') followed about a second later by a word that either was or was not congruous with the sense of the preceding phrase. The phrase that set up the context (relevant category) was spoken by the experimenter in order to engage the subject directly, whereas the ERP elicited by the 'target' word was presented visually. The subject's task was to indicate whether or not they thought the word flashed was appropriate to the context established by the preceding phrase and thereafter to say the word they had seen aloud. Separate averages were calculated for congruent and incongruent words following both the general category and antonymic (opposites) contexts. Overall, the results showed a significant reduction in the amplitude and prolongation of the latency of the N400 effect (difference between ERPs to congruent and incongruent words between 200 and 600 ms post-stimulus word onset) with age and a still further diminution of the N400 effect in the Alzheimer's patients (see Fig. 8).

Johnson (1992), likewise found the absence of an N400 in a similar paradigm in patients suffering from subcortical dementia associated with supranuclear palsy.

Neuropsychological research by Chertkow and Bub (1990) on the nature of the semantic memory impairments of SDAT patients as opposed to aphasics with anomic symptoms leads to differential predictions about the efficacy and speed of processing of words versus pictures and between items that the patients could or could not name upon exposure to a drawing of the object; these can be tested via N400 studies of the type described above. Moreover, the N400 measure would be a good way to test the proposed amodal nature of the semantic memory impairment in SDAT.

Epilogue

In recent years, ERP studies on language processing have proven to be of substantial value for testing and developing models of normal language comprehension. It was our intent in this chapter to show that the ERP technique can also become an important tool in neurolinguistic research as long as the experiments are designed to test *precise* hypotheses about the nature of the specific language process presumed to be compromised. Indeed, there is every reason to expect an increasing contribution of the ERP method to neurolinguistically motivated studies on the nature of language deficits in aphasic patients, patients with developmental or acquired dyslexia, and Alzheimer patients among others.

For example, we anticipate that the well-established finding of qualitatively different ERP correlates for certain semantic and syntactic aspects of language processing will help to tease apart semantic from strictly syntactic deficits in patients with language problems.

While there are several brain imaging techniques (e.g. ERP, MEG, PET, functional MRI) to choose from these days, the ERP remains the most sensitive index of the actual and relative timecourse(s) of different mental operations. Thus, while positron emission tomography (PET) and functional magnetic resonance imaging (fMRI) may reveal anatomical loci of increased or decreased activity, the ERP provides the high temporal resolution necessary to view the various brain processes involved in different cognitive acts. Used in combination with other brain imaging techniques, the ERP method will undoubtedly bring us closer to an understanding of how humans read, listen and speak so fast and effortlessly. Together with the well established neuropsychological research methods, ERPs also hold great promise for helping to delineate the nature of language breakdown.

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