

Perceptual and Attentional Factors in Language Comprehension: A Domain-General Approach

Jennifer Aydelott

*Birkbeck College,
University of London, UK*

Marta Kutas

University of California, San Diego

Kara D. Federmeier

*Beckman Institute,
University of Illinois at Champaign-Urbana*

INTRODUCTION

Does language possess its own distinct set of processing mechanisms, or does it share mechanisms with other cognitive processes? Traditional symbolic models of language comprehension have assumed a set of distinct processing components within a modular system (e.g., the lexicon or grammar), each subserving a language-specific function and operating on language-specific information and representations (e.g., Fodor, 1983; Grodzinsky, 1995a, 1995b, 2000; Pinker, 1994; Pinker & Ullman, 2002). According to such models, the mechanisms responsible for language comprehension are essentially separate and distinct from the mechanisms responsible for other cognitive processes, and do not share general resources with them. Further, the operation of domain-specific processing modules is thought to be impenetrable to attention and cognitive control, as well as to sources of information outside of the symbol system of that particular module (Fodor, 1983; Pylyshyn, 1980, 1984). Such models assume a static base of linguistic knowledge—i.e., linguistic competence—which is associated with distinct neural structures and may therefore be selectively disrupted by localized brain injury (Fodor, 1983). The apparent dissociations among various language impairments observed in patients with brain damage has

been offered as evidence in favor of domain-specific models, in particular the frequently cited separation of lexical-semantic and grammatical processing in certain aphasic patients (e.g., Pinker & Ullman, 1994; Ullman, 2001).

Distributive models of language comprehension have offered an alternative to the domain-specific approach. According to such models, linguistic representations are acquired and modified in both the short and long term, by means of learning mechanisms that operate across all cognitive domains, not just language (Elman, Bates, Johnson, Karmiloff-Smith, Parisi, & Plunkett, 1996). As opposed to a static, localized knowledge base, under a domain-general approach, linguistic representations (which may themselves be modality-specific) are dynamic and distributed, and are routinely subject to multiple influences and to the operation of both perceptual and higher-level cognitive processes. Thus, domain-general models have called into question the utility/validity of the distinction between competence and performance in language processing, and the characterization of language disorders in terms of damage to discrete, language-specific processing modules.

This perspective makes a number of predictions about the nature of language comprehension in normal and language-impaired populations. Rather than being restricted to a set of specialized neural substrates, language comprehension processes should engage multiple distributed brain areas, which may be involved in a variety of cognitive functions that are not specific to language. Moreover, this processing network should reflect the influence of perceptual input in the formation of higher-level linguistic representations, as well as the role of domain-general processes in activating, selecting, and maintaining these representations in the process of language comprehension. It is also possible within this theoretical framework to formulate a processing account of normal language comprehension in terms of the activation of linguistic representations on the basis of sensory input, the construction of higher-level meaning from these active representations, and the integration of subsequent input with this meaning. According to this approach, then, these aspects of language comprehension draw upon processing mechanisms, shared by other cognitive functions, such as working memory and attentional control, with the nature and accessibility of the resulting higher-level representations changing over time in response to changes in the input.

Such an account of language processing allows for the characterization of language disorders in terms of disruptions or limitations in the processing resources that are necessary to access linguistic representations and to construct higher-level meanings, rather than in terms of the disintegration or loss of the representations themselves. On this account, dissociations of apparent 'language-specific' processes may emerge merely because differ-

ent aspects of language comprehension critically depend upon different sources of information and different types of processing (for instance, some aspects of comprehension will be most dependent upon the assimilation of perceptual information, others upon attentional control, others upon working memory), and not because of damage to specific language modules. Indeed, detailed investigation of the nature of language disorders from a domain-general perspective reveals that such dissociations are not as specific as has been previously suggested, and in fact may be more easily accounted for in terms of a general processing model.

If this characterization of language disorders is correct, then it should be possible to induce similar 'domain-specific' language deficits in neurologically intact individuals by imposing various processing or capacity limits on normal processing. This view predicts that when unimpaired individuals are subjected to domain-general cognitive stress in the form of perceptual degradation, increased attentional demand, or reduced processing time, language processing may be disrupted in ways that mirror the various dissociations observed in language-disordered populations. In any case, investigating the effects of cognitive stress is likely to help clarify the specific role of perceptual and attentional factors in various aspects of normal language processing.

This chapter will present evidence that is compatible with a domain-general processing approach to language comprehension. To this end, we will examine one aspect of language comprehension, the processing of lexical-semantic information, in particular detail. Lexical-semantic processing is of particular significance to the present argument, as recent domain-specific models have argued for a distinct, specialized lexicon and grammar, subserved by neural structures in the posterior temporal and inferior frontal regions of the left hemisphere, respectively (Pinker & Ullman, 2002; Ullman, 2001). Having addressed the role of domain-general processes in grammatical comprehension elsewhere (Dick, Bates, Wulfeck, Aydelott Utman, & Dronkers, 2001), we will in the present chapter compare findings from behavioral studies of neurologically intact adults and patients with language disorders to explore the complex nature of the lexical impairments associated with brain injury, and discuss possible accounts of these impairments under a general processing approach. We will demonstrate that similar patterns of impairment may be induced in brain-intact individuals subjected to different types of perceptual and attentional stressors. Further, we will show that the dynamic nature of linguistic representations may be exploited to overcome disruptions produced by cognitive stress. In addition, we will present evidence from some neurophysiological studies demonstrating that language comprehension is subserved by a distributed processing network involving multiple brain areas in both the left and right hemispheres, with no clear distinction between perceptual and conceptual processing.

We dedicate this chapter to Elizabeth Bates, whose pioneering work in adult psycholinguistics, child language acquisition, cognitive development, and cognitive neuroscience has provided the theoretical framework in which this evidence is presented. Liz Bates has made an inestimable contribution to our understanding of language, cognition, and the brain through her unique perspective and rigorous approach to science. Her groundbreaking research and theoretical insights have been a source of inspiration to countless students and scholars throughout the world, and have shaped the contributions of those who have had the opportunity to train under her generous supervision. We are honored to contribute to this volume, and to offer this review of one of the many areas of language research upon which her work has made a lasting impact.

BEHAVIORAL STUDIES OF LEXICAL-SEMANTIC PROCESSING IN NORMAL AND LANGUAGE-IMPAIRED INDIVIDUALS

Language comprehension depends upon the activation of higher-level representations on the basis of sensory (auditory or visual) input. Access of word-level information is particularly important, as lexical representations include much if not all of the semantic and grammatical information necessary for the construction of sentence-level meaning. Most models of lexical access assume at least three stages of processing in the mapping from sensory information to word-level representations: the activation of a set of lexical candidates from acoustic or visual input; the selection from among these candidates of the best match with the input, which may require the suppression of incompatible candidates; and the integration of the associated lexical information with the ongoing sentence context (e.g., Faust & Gernsbacher, 1996; Gernsbacher, 1996, 1997; Marslen-Wilson, 1989, 1993; Marslen-Wilson & Warren, 1994). In this section, we will examine the role of perceptual input and attentional control on these aspects of lexical processing, and explore the possible neural mechanisms underlying these processes by evaluating the evidence from neuropsychological and neuroimaging studies.

Studies of semantic priming have provided a valuable means of examining the mapping from perception to meaning in normal adults and aphasic patients. In these studies, participants respond to a word target that is preceded by a prime word, which is either semantically related or unrelated to the target (e.g., CAT-DOG or RING-DOG). Participants are faster to respond to targets that are preceded by related primes than to targets that are preceded by unrelated primes (e.g., Meyer & Schvaneveldt, 1976; Neely, 1991). This semantic priming effect may be attributed to the spread of acti-

vation within the lexicon: when the lexical representation associated with the prime is activated by the sensory input, this activation is passed on to semantically related representations, including the upcoming target. Thus, when the target is encountered, it has already been at least partially activated ('primed') by the prior context (i.e., prime), and responses to the target are facilitated. Semantic priming thereby provides an implicit measure of the level of activation produced by an input.

Blumstein, Milberg, and colleagues have used the semantic priming effect to examine the influence of perceptual information on semantic activation in a series of recent studies. Specifically, these studies were designed to explore the role of acoustic-phonetic variation in the mapping from sound to meaning. Blumstein and Milberg set out to determine whether variations in the sensory input would directly influence lexical activation levels, by manipulating phonetic segments in a prime word and measuring the effects on responses to related targets (Milberg, Blumstein, & Dworetzky, 1988). They compared reaction times (RTs) in an auditory lexical decision task to target words preceded by related primes relative to unrelated primes (in this case, phonologically permissible nonwords), to establish a baseline measure of semantic priming (CAT-DOG vs. PLUB-DOG). In addition, they included conditions in which a phonetic segment in the prime word was replaced with another segment that differed from the original sound by one phonetic feature (e.g., GAT-DOG, a change in voicing) or by two or more features (e.g., WAT-DOG, a change in voicing, place, and manner). The results revealed that the phonetic manipulations reduced semantic priming with the size of the reduction related to the degree of phonetic distance between the intact and altered prime words (i.e., WAT produced less priming than GAT, which produced less priming than CAT). If the magnitude of the semantic priming effect is a reflection of the amount of lexical activation that a sensory input produces, these findings suggest that inputs that are a partial match for a word form result in partial activation, and that the level of activation is dependent upon the degree of similarity between the input and the word form. Thus, sensory input produces a graded response at the lexical level.

This interpretation is supported by more recent studies investigating the effects of acoustic variation below the level of the phonetic segment and on semantic priming. Andruski, Blumstein, & Burton (1994), for example, manipulated voice-onset time, the primary cue to the voicing contrast in initial stop consonants (e.g., 'ka' vs. 'ga'), to produce segments that were poorer acoustic exemplars of the voiceless stop category while still being consistently identified as members of that category. They compared the amount of semantic priming produced by a prime word containing a good acoustic exemplar (CAT-DOG) with the amount of priming produced by the same word containing a poorer exemplar (C*AT-DOG), relative to an unrelated

prime (RING-DOG). At a brief inter-stimulus interval (ISI) of 50 ms, the results were similar to the findings of Milberg et al. (1988): prime words containing poorer acoustic exemplars produced significantly less semantic priming than prime words containing good acoustic exemplars. Interestingly, nonwords presented in similar prime conditions (e.g., COAT-PLUB vs. C*OAT-PLUB) did not show an increase in RTs for targets following altered primes, demonstrating that the effect is not due to a general slowing in virtue of the processing of poorer acoustic exemplars. Further, the reduction in priming could not be attributed to competition at the lexical level: similar effects were produced by potentially ambiguous prime words (e.g., C*ANE-STICK, where a change in the phonetic category of the altered segment would result in a word, 'gain') and unambiguous words (e.g., C*AT-DOG, where a change in category would not result in a word). Thus, the results appear to reflect the goodness-of-fit between acoustic input and lexical form, rather than the activation of multiple lexical entries. Finally, the effects of acoustic variation on lexical activation are short-lived: no difference in priming was observed between altered and unaltered prime words at a longer ISI of 250 ms, suggesting that acoustic variation is accommodated with additional processing time. Thus, the lexical candidate that is the best match with the acoustic input will eventually become fully activated. We have since obtained similar results in our own research for a variety of acoustic cues to phonetic contrasts in initial, medial, and final position in prime words (Aydelott Utman, 1997; Aydelott Utman, Blumstein, & Sullivan, 2001).

These findings have possible implications for domain-specific models of lexical access. Specifically, the results suggest that perceptual information maps directly onto lexical representations during language comprehension, such that partial information produces partial activation. Thus, there is a direct relationship between the sensory input and the activation of word-level information. This would appear to contradict modular accounts of language comprehension, which argue for shallow information transfer between levels of processing, such that perceptual processes yield abstract outputs which serve as inputs to higher-level processing (Fodor, 1983). These results suggest that it is the sensory information itself, rather than an abstract phonetic code, that serves to activate lexical representations, and that lexical activation is graded to reflect the degree of match between sensory input and word form.

The semantic priming paradigm has also been used to explore the nature of lexical processing in patients with language disorders. Domain-specific models have assumed a strict separation between lexical processing and other aspects of language comprehension, such as grammatical processing (Grodzinsky, 1995a, 1995b, 2000; Pinker, 1994; Pinker & Ullman, 2002). Further, according to such models, lexical and grammatical proc-

esses are associated with distinct neural structures that subserve language-specific functions, which may be selectively impaired as a result of focal brain injury. The classical distinction between Broca's and Wernicke's aphasia would appear to provide compelling evidence for these claims. According to the traditional characterization of these disorders, patients with Broca's aphasia experience a loss or disruption of grammatical rules resulting from damage to left inferior frontal brain regions; this produces a deficit in syntactic comprehension ('agrammatism'). By contrast, patients with Wernicke's aphasia experience a loss or disruption in lexical-semantic representations resulting from damage to left posterior temporal brain regions; this produces a deficit in semantic comprehension (Ullman, 2001). As described above, this apparent double dissociation suggests the operation of functionally distinct, specialized neural modules for lexical and grammatical representations.

This characterization of Broca's and Wernicke's aphasia makes clear predictions about the nature of lexical comprehension in these groups. Specifically, Wernicke's aphasics should demonstrate marked impairment in all tasks requiring lexical-semantic processing, whereas performance on the same tasks should be relatively unimpaired in Broca's aphasics. Off-line measures of semantic comprehension have tended to support these predictions. Wernicke's aphasics tend to make semantic errors on word-picture matching tasks (Goodglass & Baker, 1976) and fail to demonstrate normal semantic category structure in semantic similarity judgments (Zurif, Caramazza, Myerson, & Galvin, 1974); in contrast, Broca's aphasics show relatively spared performance on these tasks. Further, when asked to judge whether two visually presented words are semantically related (e.g., CAT-DOG vs. RING-DOG), Wernicke's aphasics demonstrate poor performance relative to normal individuals, whereas Broca's aphasics are not significantly impaired (Milberg & Blumstein, 1981).

The evidence from semantic priming studies, however, reveals a more complex picture of lexical processing in these two patient populations. Blumstein, Milberg, & Shrier (1983) presented a lexical decision task to Broca's and Wernicke's aphasics, in which word targets were preceded by semantically related and unrelated primes. Similar to normal subjects, Wernicke's aphasics demonstrated significant semantic priming for targets preceded by related primes. This finding has been observed in numerous studies using various priming methodologies, including list priming, in which primes and targets are presented in a list and lexical decision responses are made to each item (e.g., DOG-CAT-RING-PLUB etc.; Milberg & Blumstein, 1981) and triplet (summation) priming, in which the target is preceded by two prime words (e.g., COIN-BANK-MONEY; Milberg, Blumstein, & Dworetzky, 1987). These results are in marked contrast to the performance of Wernicke's aphasics on explicit re-

latedness judgments, and demonstrate that lexical-semantic knowledge is intact in these patients.

In contrast to Wernicke's aphasics, Broca's aphasics show weak, unreliable, or absent semantic priming under the same conditions, despite their relatively spared performance on semantic judgment tasks (Milberg & Blumstein, 1981; Blumstein, Milberg, & Shrier, 1983). Interestingly, Broca's aphasics fail to show priming in paradigms in which there is no predictable relationship between the prime and the target, such as list and triplet priming (Milberg & Blumstein, 1981; Milberg, Blumstein, & Dworetzky, 1987; Prather, Zurif, Stern, & Rosen, 1992), and exhibit weak priming effects in paired priming paradigms (Blumstein, Milberg, & Shrier, 1983). This suggests that Broca's aphasics show priming only when it is possible to generate a response strategy based on semantic relatedness and/or expectancy, whereas priming in Wernicke's aphasics reflects automatic spreading activation within the semantic network (cf. Milberg & Blumstein, 2000; Milberg, Blumstein, Katz, Gershberg, & Brown, 1995). This interpretation is supported by more recent findings that Broca's aphasics are sensitive to factors that influence expectancy in paired priming tasks, such as the proportion of semantically related pairs in the stimulus set and the length of the interstimulus interval (ISI), whereas Wernicke's aphasics are not (Blumstein et al., 1995). Thus, it appears that both Broca's and Wernicke's aphasics are impaired in the processing of lexical-semantic information, but that the nature of this impairment differs markedly across the two groups: Wernicke's aphasics have difficulty making explicit judgments of semantic relatedness, but are not impaired in the automatic activation of semantically related items, whereas Broca's aphasics have no difficulty in judging relatedness, but show a pronounced deficit in automatic activation (cf. Blumstein, 1997; Blumstein & Milberg, 2000).

This contrast is further supported by studies of the mapping from sound to meaning in these patient groups. Milberg, Blumstein, & Dworetzky (1988) compared the performance of Broca's and Wernicke's aphasics on the phonetic distortion paradigm described above, in which word targets were preceded by intact and phonetically distorted related primes (e.g., DOG preceded by CAT, GAT, or WAT) as well as unrelated primes (e.g., PLUB). In contrast to normal subjects, who show a graded response to phonetic distortion, Broca's and Wernicke's aphasics demonstrate two distinct patterns of performance in response to these stimuli. Broca's aphasics show significant priming only in the phonetically intact prime condition (CAT-DOG), and show no priming for phonetically distorted primes (GAT-DOG or WAT-DOG) relative to unrelated primes. Wernicke's aphasics, on the other hand, show significant priming in both intact and distorted prime conditions, with no significant differences in priming between intact and distorted primes (i.e., CAT, GAT, and WAT all produce similar levels of priming to the

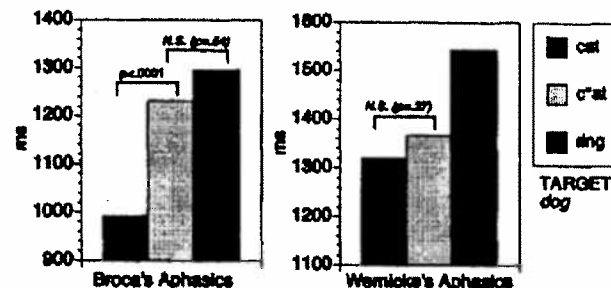


FIG. 11.1.

target DOG, relative to the unrelated prime). Thus, for Broca's aphasics, only exact overlap between sensory input and word form is sufficient to produce lexical activation, whereas for Wernicke's aphasics, any overlap between input and form is sufficient to fully activate a lexical representation.

We have since obtained similar results in studies of subphonetic variation and priming in these patient groups (Aydelott Utman, 1997; Aydelott Utman, Blumstein, & Sullivan, 2001). In these studies, targets were preceded by related primes containing phonetic segments that were either intact (e.g., CAT-DOG) or altered to produce poorer acoustic exemplars (e.g., C*AT-DOG), as well as by unrelated primes (e.g., RING-DOG). Whereas normal subjects show a graded priming effect in response to these stimuli, Broca's aphasics (Fig. 11.1, left panel) show significant semantic priming only for intact primes (CAT-DOG), and no priming for altered primes (C*AT-DOG), relative to unrelated primes. In contrast, Wernicke's aphasics (Fig. 11.1, right panel) show significant priming for both intact and altered primes relative to unrelated primes, with no significant difference in the magnitude of priming between the intact and altered conditions. Interestingly, unlike normal subjects, Broca's aphasics are influenced by both lexical competition and the locus of the acoustic distortion in the prime word (Fig. 11.2). Specifically, the effect of acoustic manipulation is most pronounced in Broca's aphasics when a change in the identity of the distorted segment would produce a real word (e.g., C*ANE-STICK, as opposed to C*AT-DOG), and when the manipulation occurs at the onset of the prime word rather than the offset (e.g., C*AT-DOG, as opposed to RUG*-FLOOR). Wernicke's aphasics show no effect of acoustic manipulation, irrespective of the locus of the manipulation in the prime word, or its potential effect on the lexical status of the prime.

Taken together, the results presented above suggest a possible account of the lexical comprehension impairments in Broca's and Wernicke's aphasia in terms of a general processing model of aphasic deficits. Blumstein and Milberg (2000) have argued that the pattern of performance observed

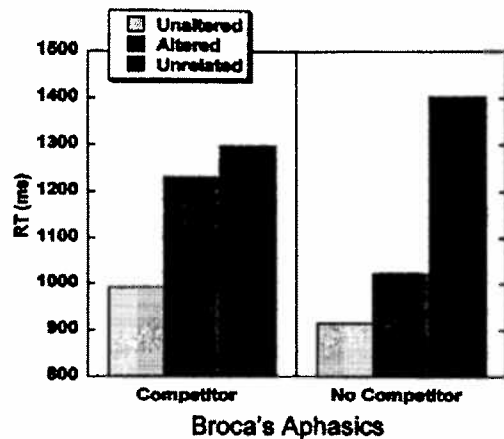


FIG. 11.2.

in these two groups reflect deficits in the activation and inhibition of lexical candidates during on-line processing. According to this view, in normal language comprehension, the sensory input activates a set of possible lexical candidates depending upon the degree of overlap between input and word form, and inhibits those lexical items that are incompatible. Broca's aphasics appear to be impaired in the activation of lexical representations, such that the sensory input fails to produce the same level of activation as in normal subjects. Thus, Broca's aphasics achieve lexical activation only when there is an exact match between input and word form. Further, Broca's patients fail to show graded activation when there is partial overlap between input and form, particularly when the input overlaps with more than one lexical representation, and they have difficulty overcoming acoustic mismatch that occurs early in a word. In contrast, Wernicke's aphasics appear to have difficulty inhibiting lexical entries that are incompatible with the acoustic input, resulting in overactivation of candidates when there is only partial overlap between input and word form.

This characterization of lexical processing in Broca's and Wernicke's aphasia is compatible with the previous observation that Broca's aphasics are spared in explicit semantic judgments and controlled processing strategies and impaired in automatic activation, whereas Wernicke's aphasics show the reverse pattern of deficit (Blumstein et al., 1995). Activation and inhibition have been associated with differing degrees of attentional load in semantic priming studies. Specifically, activation has been associated with facilitation of congruent targets in priming studies, which occurs at very brief ISIs and may be observed even when participants report no explicit awareness of the prime stimulus, as in masked priming paradigms (see

Neely, 1991, for review). In addition, as observed above, early facilitation effects are particularly sensitive to variations in the sensory input (Andruski, Blumstein, & Burton, 1994; Aydelott Utman, Blumstein, & Sullivan, 2001; Neely, 1991). On the other hand, inhibition of incongruent targets tends to emerge only at longer ISIs, and is associated with the generation of expectancies and the operation of heuristic strategies (Neely, 1991). Further, inhibition effects tend to be reduced in populations with limited attentional resources (e.g., Gernsbacher, 1997). Thus, it appears that lexical activation is a rapid, automatic process that depends on sensory information, whereas inhibition occurs later in processing and is more demanding in terms of attentional resources. The performance of Broca's and Wernicke's aphasics on tests of lexical processing may therefore be characterized in terms of general deficits in the automatic and controlled aspects of lexical access, respectively (cf. Blumstein, 1997).

The claim that facilitation and inhibition effects reflect separate processes, each with a different time course and a different degree of attentional load, suggests that these effects may respond selectively to different types of cognitive stress. Specifically, facilitation effects should be particularly vulnerable to manipulations of the perceptual input, whereas inhibition effects should be disrupted by increased attentional demand or decreased processing time. Thus, it should be possible to induce selective disruptions in the facilitation and inhibition of lexical items in neurologically intact individuals by imposing perceptual and attentional stress during language comprehension. We explored these predictions in a recent study (Aydelott & Bates, 2004; cf. Aydelott Utman & Bates, 1998) using a contextual priming paradigm. Participants made lexical decision responses to word targets (e.g., COW) which appeared in highly constraining sentence contexts (>90% cloze probability) that were congruent (e.g., *On the farm the farmer gets up early to milk the—*), incongruent (e.g., *Since everyone kept walking into my room I decided to lock the—*), or neutral (e.g., *Its name is —*) with respect to the meaning of the target word. Acoustic distortions were applied to the sentence context in each semantic bias condition, and the effects of these manipulations were evaluated relative to subjects' performance when the context was acoustically intact. Two types of distortion were applied: a perceptual distortion (low-pass filtering at 1 kHz), which was intended to interfere with the intelligibility of the acoustic signal and disrupt facilitation of congruent targets; and an attentional distortion (time compression, which speeded sentence presentation rate by 50%), which was intended to reduce processing time and disrupt inhibition of incongruent targets. Facilitation and inhibition effects were measured by comparing RTs in the biasing conditions with RTs to the same targets in the neutral condition.

The results for intact sentence contexts (Fig. 11.3) revealed that the semantic bias produced both facilitation (faster RTs for congruent targets)

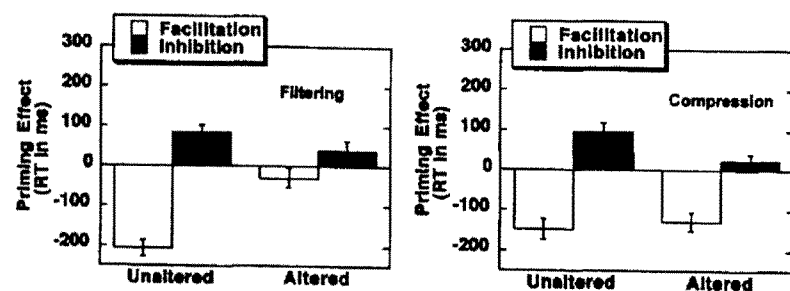


FIG. 11.3.

and inhibition (slower RTs for incongruent targets), relative to the neutral baseline. The acoustic manipulations produced different patterns of results depending upon the nature of the distortion. As predicted, perceptual distortion (filtering) reduced the facilitation effect produced by congruent contexts, whereas attentional distortion (compression) reduced the inhibition effect produced by incongruent contexts without affecting facilitation. Neither of the acoustic manipulations significantly influenced responses to targets in the neutral condition, indicating that the extent to which distortion influences priming is dependent upon the degree of semantic bias introduced by the context.

We have obtained similar findings in studies of the effects of competing speech on contextual priming (Moll, Cardillo, & Aydelott Utman, 2001; Cardillo, 2004). Interference from a competing speech signal represents a particularly complex source of cognitive stress, with a number of possible implications for language comprehension. Competing speech places an increased demand on processing resources, as the listener must selectively attend to one signal while suppressing another. Further, competing speech may also be relatively more demanding than a competing signal with no semantic content, because the speech signal will activate linguistic representations that are in conflict with the attended signal. In addition, competing speech may also affect the perceptibility of the attended signal by masking the spectral frequencies of the signal, thereby interfering with the encoding of the sensory input.

In order to separate the specific contributions of the perceptual, attentional, and semantic interference introduced by competing speech, participants were presented with a similar sentence-word priming paradigm to that described above, with four interference conditions (Moll, Cardillo, & Aydelott Utman, 2001; Cardillo, 2004). In the first condition, the sentence context (congruent, incongruent, or neutral) was presented in one ear, and a competing speech signal was presented in a different ear, so that the target signal could be isolated from the competing signal by attending selectively to one auditory channel. The second condition was identical to the

first, with the exception that the competing speech signal was presented backward. Backward speech has the same spectral and temporal characteristics as forward speech, but contains no semantic content, allowing for an evaluation of the effects of selective attention in the absence of a competing semantic message. In the third and fourth conditions, the competing speech signals (forward and backward, respectively) were presented in the same ear as the target signal. In contrast to the different ear conditions, in the same ear conditions it was not possible to isolate the target signal by attending selectively to one ear. Thus, the perceptual interference from the competing signal was greater in the same ear conditions. It was predicted that, when the competing signal was presented to a different ear, attending to one auditory channel would increase the demand on processing resources, thereby disrupting the inhibition of incongruent targets, whereas in the same ear conditions, perceptual masking of the target signal by the competing signal would disrupt the facilitation of congruent targets. It was possible to determine whether the observed effects were due to the semantic content of the competing signal or to the presence of the signal itself by comparing the patterns of performance in the forward and backward speech conditions.

Results revealed that, as predicted, when forward speech is presented to a different ear from the target signal (Fig. 11.4, top panel), inhibition of congruent targets is significantly reduced, whereas facilitation is unaffected. However, when backward speech is presented to a different ear (Fig. 11.4, bottom panel), neither facilitation nor inhibition are affected, demonstrating that the interference produced by competing speech is a consequence of the semantic content of the competing signal, rather than the presence of the signal itself. When forward speech is presented to the same ear (Fig. 11.5, top panel), facilitation of congruent targets is significantly reduced. A similar pattern is observed when backward speech is presented to the same ear (Fig. 11.5, bottom panel), suggesting that the effects of perceptual masking do not depend upon the semantic content of the competing signal; however, it appears from these data that the reduction in facilitation is slightly less for backward than forward speech presented to the same ear. Nonetheless, this interaction did not reach significance and will be explored further in future research.

Taken together, the results of the behavioral studies presented above provide a picture of the component processes involved in the recognition of words in a semantic context. A set of candidate lexical representations is activated on the basis of the perceptual input, and initial activation levels are determined by the extent to which the sensory information matches a particular word form representation in the lexicon. The semantic context may also serve to activate compatible lexical entries, or to facilitate the selection of compatible entries. These represent early, automatic processes

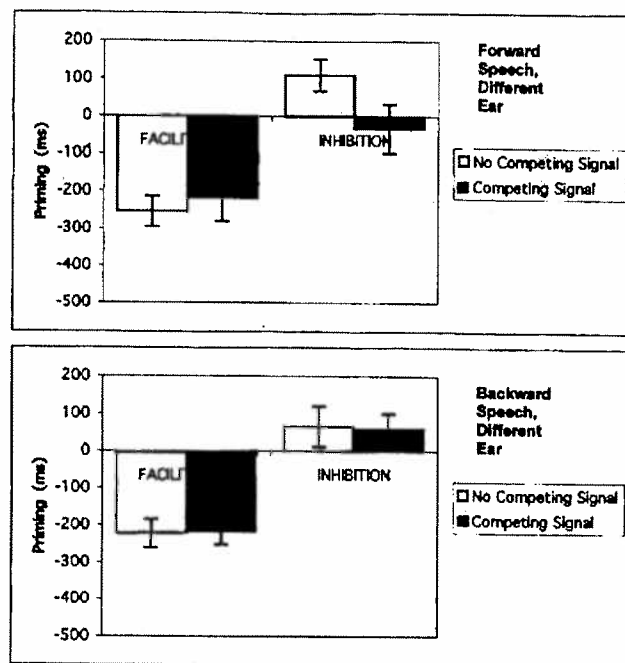


FIG. 11.4.

that place relatively few demands on processing resources. Once initial activation has occurred, the most appropriate lexical candidate must then be selected from among the active candidates, which involves the inhibition of candidates that are incompatible with the sensory input and/or the semantic context. The selected item must then be integrated into the overall meaning of the sentence. Selection and integration are later-occurring, controlled processes that are associated with increased attentional demand.

Although the behavioral studies reported above offer valuable insights into the role of perceptual and attentional factors in lexical-semantic comprehension, the methodology requires that the underlying neural processes involved in these aspects of comprehension be inferred on the basis of the nature of the experimental manipulations and (in the case of neuropsychological investigations) the location of the lesion that produces the corresponding behavior. Thus, reaction time measures can tell us that perceptual and attentional factors have specific, predictable effects on behavior, but we must speculate as to the precise origins of these effects based upon the circumstances under which they emerge. In contrast, electrophysiological methods provide a direct measure of neural activity in response to experimental manipulations, and are therefore an invaluable

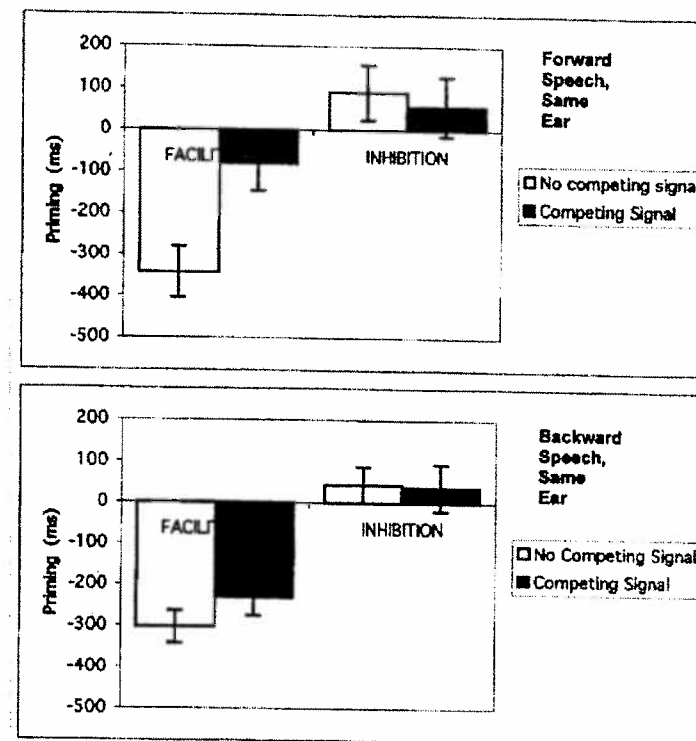


FIG. 11.5.

means of establishing in more detail the neural mechanisms responsible for expectancy generation, perceptual analysis, semantic activation, and contextual integration in language comprehension, and the extent to which these reflect language-specific processes.

ELECTROPHYSIOLOGICAL APPROACH TO THE DOMAIN-SPECIFICITY OF LANGUAGE PROCESSING

The idea that language processing, while quite special in many ways, may not rely on its own domain-specific set of specialized psychological or neural mechanisms but rather may share one or more basic mechanisms with other cognitive domains has emerged independently and in parallel from within the field of cognitive electrophysiology. Cognitive electrophysiology is a research area at the interface between cognitive/experimental psychology and neuroscience in which brain measures are used to make inferences

about psychological phenomena. Specifically, its practitioners make use of systematic changes in the pattern of electrical brain activity—event-related brain potentials or ERPs—recorded at the scalp of brain intact individuals as they sense, perceive, transform, encode, and/or respond to sensory inputs. The beauty of this particular neuroimaging technique is that it is a direct measure of ongoing neural activity that is so exquisitely sensitive to sensory, cognitive, emotional, memory, and motoric factors that it would be a valuable dependent measure even if it were not generated in the brain; but, of course, it is.

Brain cells communicate via electrochemical signals, and these can be monitored noninvasively across the entire surface of the scalp as they occur. Under normal (non-stimulated) conditions, each neuron has a “resting” electrical potential that arises due to the distribution of positive and negative elements (ions) inside and outside it. Stimulation of the neuron, as by sensory input, changes the permeability of the neural membrane to these charged elements, thereby altering the electrical potential. A transient increase in potential (depolarization) at the cell body can cause an all-or-none “action potential,” a wave of depolarization that moves along the cell’s axon. The action potential can then be spread to other neurons via the release of chemicals (neurotransmitters) from the axon tip that travel in the extracellular space and cause permeability changes in the dendrites of nearby neurons. These permeability changes may cause an action potential in the receiving cell, or may just alter the electrical potential of that cell such that it will be more or less sensitive to other stimulation. In either case, these “post synaptic potentials” can be recorded at the scalp, thereby providing an instantaneous record of neural processing even when this activity does not lead to any overt response. Neural communication thus involves the flow of charged particles across neural membranes, which generates an electric potential in the conductive media inside and outside the cell; these current flows are the basis for electrophysiological recordings in the brain and at the scalp surface. More specifically, it is believed that much of the observed activity at the scalp emanates from cortical pyramidal cells whose organization and firing satisfies the constraints for an observable signal (see, e.g., Allison, Wood, & McCarthy, 1986; Kutas & Dale, 1997; Nunez & Katznelson, 1981 for more detail).

Researchers interested in unresolved issues within the domain of language thus tend to measure changes in the electrical brain activity as individuals read or listen to words, word pairs, sentences, or short stretches of discourse, or as they view pictures embedded in language contexts or within a series of pictorial images, and as they perform tasks ranging from reading/listening/viewing for comprehension to answering questions, making grammaticality, plausibility or categorical judgments, or performing some non-language task with language materials. From systematic changes in the pat-

tern of electrical brain activity elicited by words and pictures under such circumstances, it has proven possible to track visual and auditory input from sensory transduction to the laying of a memory trace to the moment either makes available the knowledge to which it is linked as it enables the processes involved making sense.

Investigations of the neural basis of language processing have generally focused on the brain’s response to particular events or kinds of events, such as the appearance of a word, picture, sentence or scene on a computer screen or over headphones. To examine event-related activity of this type, one typically averages the electrical signal time-locked to the event (stimulus) of interest to create an “event-related (brain) potential” or ERP—a waveform of voltage fluctuations in time, one for each recording electrode across the head. Each waveform consists of a series of positive- and negative-going voltage deflections (relative to some baseline activity prior to event onset); experimental factors, among others, are reflected in the morphology (shape) of the waveform (e.g., presence or absence of certain peaks), the latency, duration, or amplitude (size) of one or more peaks, or their amplitude distribution over the scalp.

ERPs are useful measures for the study of information processing in general, and language processing in particular, because they are a continuous, multidimensional signal. Specifically, they offer a direct estimate of what a significant part of the brain (even if we cannot infer from this measure alone precisely which part) is doing just before, during, and after an event of interest, even if it is extended in time. And they do so with millisecond resolution. This temporal sensitivity is crucial given that many important cognitive operations transpire in less time than it takes to react to a predictable sensory stimulus (i.e., a simple reaction time). At minimum, ERPs can indicate not only that two conditions differ, but reveal something about the nature of the difference—i.e., whether, for example, there is a quantitative change in the timing or size of a process or a qualitative change as reflected in a different waveform morphology or scalp distribution. To a limited extent, ERPs also can be used to examine where in the brain processes take place (via source modeling techniques and in combination with other neuroimaging techniques; for more information see review by Kutas, Federmeier, & Sereno, 1999; also Dale & Halgren, 2001), though this is not the primary aim of most ERP investigations.

Using ERP techniques, researchers have looked at language processing from early stages of word recognition through the processing of multi-sentence discourses, from the planning of a speech act to its articulation (e.g., Kutas & Van Petten, 1994; Osterhout, 1994; Osterhout & Holcomb, 1995). In doing so, one finds that the brain’s processing of language involves many different kinds of operations taking place at different times and different temporal scales, varying in the extent to which they are gen-

eral purpose. Indeed, it can be argued that one of the most remarkable findings in the cognitive electrophysiology of language processing has been that none of the ERP effects discovered to date seems to be unique to language processing. While several ERP components such as the N400 (Kutas & Hillyard, 1980), left anterior negativity (LAN), or P600 (Osterhout & Holcomb, 1992; Munte, Heinze, Matzke, Wiering, & Johannes, 1998) have proven very useful as dependent measures that are sensitive to some important aspect of language processing, none of them seem to be language-specific (definitions aside).

The ERP technique is in fact especially amenable to looking for commonality of neural (mental) operations, because the brain's response to any given event (stimulus, response) unfolds in time as the event makes its way from the sensory receptors to the lower, intermediate, and higher-order processing areas of the brain, and back—feedforward and feedback paths. It is thus possible to catalog whether or not an event is anticipated, sensed and perceived, attended to, identified, recognized as recent, old or new, considered as (im)probable, (in)frequent, surprising, informative, congruent with the ongoing context, meaningful, and/or grammatically well-formed, among others, as well as to determine the various sensory and biological factors that influence how and when these operations are carried out. In so doing, researchers can determine just how far one can get in explaining various language phenomena in terms of basic perceptual, conceptual, and motoric processes.

Even before any stimulus or event occurs, it is possible to observe some evidence at the scalp that an individual is expecting some event—a slow growing negativity originally known as the expectancy wave or the contingent negative variation (CNV) to highlight the finding that it is the contingency between two successive events and not the processing of either event *per se* that is critical for its elicitation; the CNV has been analyzed into functional subcomponents (e.g., O-wave, E-wave, readiness potential, stimulus-preceding negativity). The CNV, like so many other ERP components, varies systematically in its distribution across the scalp as a function of input modality, task parameters, and response requirements—in auditory tasks the CNV is more frontal, in tasks requiring a response it is more central, in visual tasks it is more posterior, etc. In fact, it is the functional invariance and systematic sensitivity to certain stimulus and response parameters in the face of such topographical variance that has made endogenous ERP (sub)components so useful in analyzing the information processing transactions in the brain. Any warning event (overt or internally-generated) will trigger a slow rising negativity that will last until the anticipated event occurs—its presence reflects an individual's anticipation of or expectancy for some event (even when it does not always occur), its distribution reflects the nature (e.g., modality) of the anticipated event, its shape in time the du-

ration of the interval over which the anticipation builds, and its amplitude reflects the a variety of factors such as motivation, presence of distracting stimuli, difficulty of upcoming stimulus processing (for review see McCallum & Curry, 1993).

Motor anticipation is reflected in a similar slow rising negativity largest, at least for hand movements, over the contralateral motor cortex. The asymmetric portion of this brain potential, known as the lateralized readiness potential (LRP), has been used to ask many questions about the timing of information flow through the nervous system, as it reflects preparation for making a motor response even if the movement is never actually made (for review Coles, 1989). Within the domain of language, the presence or absence of the LRP on no-go trials (when in a go/no-go paradigm) has been used to infer the order of conceptual/semantic, grammatical, and phonological operations during language production (e.g., Van Turenout, Hagoort, & Brown, 1998).

Other slow negative waves have been observed in a variety of contexts, including during attention tasks (processing negativity or Nd), short term memory scanning, mental rotation, the anticipation of feedback, long term memory retrieval, and working memory use (associated with left anterior negativity or LAN), among others (for reviews see Birbaumer, Elbert, Canavan, & Rokstroh, 1990; Haider, Groll-Knapp, & Ganglberger, 1981; McCallum & Curry, 1993). These slow waves seem to have a topography that reflects stimulus content/modality—semantic with a frontal maximum, mental rotation with more parietal maximum. Like the CNV, the amplitude of these slow waves is related to task difficulty or amount of processing effort. In short term memory scanning tasks, for example, the associated slow negativity increases in amplitude with increasing memory load (Wijers, Otten, Feenstra, Mulder, & Mulder, 1989). In mental rotation tasks, the negativity increases in amplitude with the angular disparity between the objects being compared (e.g., Roesler, Schumacher, & Sojka, 1990). And, in like fashion, in language tasks the amplitude of a slow negativity varies with the number of possible co-referents for an anaphor (van Berkum, Brown, Hagoort, & Zwitserlood, 2003). Finally, it appears that the duration of these negativities reflect the duration of particular processing stages. The processing negativity (Nd) observed in selective attention tasks is maintained as long as information in the attended channel is being analyzed and discriminated from that of a channel competing for attention (e.g., Hillyard & Hansen, 1986). Roesler and colleagues have described very similar slow negative potentials that are temporally related to the process of information retrieval from long-term memory (Roesler & Heil, 1991; Roesler, Heil, & Glowalla, 1993). These negativities persisted from the appearance of a memory probe until a response indicating the search was over. The amplitudes of these negativities were related to the difficulty of the retrieval process, though they

vary in their scalp distribution in a manner consonant with the functional division of the cortex according to lesion data. It is not a far stretch to characterize the slow negativities that are seen in association with certain sentence types in which some information must be held in working memory (e.g., object relatives, *wh*-questions, anaphoric reference) in a similar fashion (King & Kutas, 1995; Kluender & Kutas, 1993; Mueller, King & Kutas, 1997; Streb, Roesler, & Hennighausen, 1999; Vos, Gunter, Kolk, & Mulder, 2001; Weckerly & Kutas, 1999); indeed, this may explain their variable durations and varying scalp topographies across reports despite their localizing name—the left anterior negativity. On this account the LAN, though useful to examine various linguistic structures, merely reflects the use of (short-term/working) memory during language processing and not a language specific operation (e.g., Friederici, Hahne, & Mecklinger, 1996).

Anticipation, expectancy, and prediction also can be inferred from a whole host of ERP components that indicate some form of “surprise” when the expected event does not occur. There are many different ERP components that seem to reflect processes of this ilk though at different levels of the psychological and neural processing systems: the omitted stimulus potential (indexes absence of a stimulus in a temporally regular series), the mismatch negativity or MMN (reflects detection of a change in a stimulus or stimulus sequence held in auditory short term memory), P3a (indexes novelty), P3b (indexes decision making and binary categorization), N400 (reflects degree of semantic congruence), and P600 (reflects the detection of structural violations in, e.g., language and music contexts), among others. While each of these potentials could be described as indexing some aspect or type of “surprise” by virtue of a “mismatch” with or “change” from an expectation, each of them is more than simply a novelty, a surprise, or a change detector; i.e., they are not interchangeable brain events indexing interchangeable mechanisms. As such, each reveals something different about human neuromental processing. At minimum they are distinct in that the stimulus parameters and experimental setup needed to elicit them differ widely. Additionally, they reflect mental operations that differ in the extent to which they are affected by context (and what type of contexts they are sensitive to), and in the extent to which they interact with one another in space and time (see Federmeier, Kluender, & Kutas, 2002). At the same time, however, none of them is domain-specific, at least not if the domains are, say, language and non-language processing. This has practical consequences for experimental designs and is one of the primary reasons that cognitive electrophysiologists have come to the conclusion that language, though special, is *not* unique at the level of the mental operations and the brain processes that support it.

Whether or not an item is anticipated wholly or in part, once it is occurs it must be ignored or analyzed (with features extracted) to some degree,

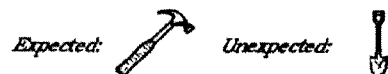
depending on how much attention it captures or has allocated to it. These sensory and attentional processes are reflected in the ERP componentry—such as the P1, N1, and P2—within the first 200 ms post-stimulus onset as the brain is determining just what it is sensing and perceiving (e.g. a letter string, a word, an object, a meaningful sound, etc.). Some aspects of (especially early) perceptual processing are likely to be similar regardless of the nature of the stimulus at least until the brain “knows” what kind of stimulus it is. Processing decisions also may be guided about what the stimulus is likely to be, based on guesses informed by frequency, recency, and predictive regularities, including the context. Whenever possible, both top-down (expectancy or context-based) and bottom-up (stimulus-based) information seem to influence brain analysis of sensory input.

The hierarchical organization of the primate visual system with its massive feedforward, lateral, and feedback connections provides the anatomical substrate for significant information/neural flow and interaction between top-down conceptual and bottom-up perceptual levels of processing. Indeed, the majority of the synaptic connections onto neurons even in primary visual cortex come from higher-order processing brain areas rather than directly from the sensory receptors *per se*. Presumably, this high density of “top-down” connections allows the analysis of visual input such as words and pictures to be shaped by factors such as prior experience, attention, and expectancy throughout the visual system up through the initial memory link or trace via the hippocampal formation. When, how, and how much such top-down information impacts perceptual and conceptual processes remains underspecified, especially for human visual processing. We (Federmeier & Kutas, 1999a, 1999b, 2001, 2002) have begun to examine this in a series of ERP studies designed to monitor top-down influences on the processing of pictures of familiar objects embedded in language contexts. We chose language contexts precisely because we believe that they can be used to establish expectations at various levels. In these studies, we embedded pictures in sentence contexts and manipulated a number of variables that we presumed would, to varying degrees, influence the nature and degree of top-down processing: (1) the participant’s experience with a particular picture, which presumably influences the picture’s perceptual familiarity and/or predictability; (2) the congruency of the picture with the prior context; and (3) the strength of that context. In one study, we also employed visual half-field presentation methods to examine issues of hemispheric involvement. For each of these studies, we also conducted a strictly word version against which the pattern of effects for pictures could be compared and contrasted in order to assess which factors were specific to language and which were not.

A total of 54 college-aged volunteers (half women) participated in the three picture studies (18 in each). All the participants were right-handed,

HIGH CONSTRAINT

Tina lined up where she thought the nail should go.
When she was satisfied, she asked Bruce to hand her the



LOW CONSTRAINT

As the afternoon progressed, it got hotter and hotter.
Keith finally decided to put on a pair of



FIG. 11.6.

monolingual English speakers with normal or corrected-to-normal vision and no neurological problems. The stimuli consisted of 176 sentence pairs, ending with either a congruent or an incongruent line drawing (50% each type). Approximately half of the sentence contexts were highly constraining for the final word of the second sentence in the pair (cloze probability > 78%) while the remaining half were less constraining (cloze probability 17%–78%) as shown in Fig. 11.6.

Participants read the sentence contexts word by word for comprehension while their electroencephalogram (EEGs) were collected from 26 recording sites distributed equidistantly across the scalp. Sentence-final line drawings were presented either at fixation (for 500 ms) or, in the hemi-field study, with nearest edge two degrees to the right or left of fixation (for 200 ms). Trials containing eye movements, blinks, or other artifacts were rejected off-line. In the *familiar condition*, participants were pre-exposed to the pictures (once each) prior to the experimental session, while in the *unfamiliar condition*, participants saw the pictures for the first time in the sentence contexts.

As expected, pre-exposure affected the amplitude of the early sensory components of the visual evoked potential (e.g., P1, N1, P2). In other words, a single exposure sufficed to impact the earliest sensory processing of the visual input. This can be best seen in a comparison of the ERPs to pictures viewed for the first time (unfamiliar pictures) overlapping the ERP to pre-exposed pictures being viewed a second time (familiar pictures), collapsed across congruency (expectancy), shown in Fig. 11.7. This comparison reveals that pre-exposure was associated with a reduction in the amplitude of the N1 component at recording sites over the front of the head (see left top) and the P1 and P2 components at recording sites over the back of the head (see right bottom). In a number of ERP studies of attention, the frontal N1 has been linked to allocation of visuospatial attention; more specifically, it has been hypothesized to reflect the output of a capacity-limited

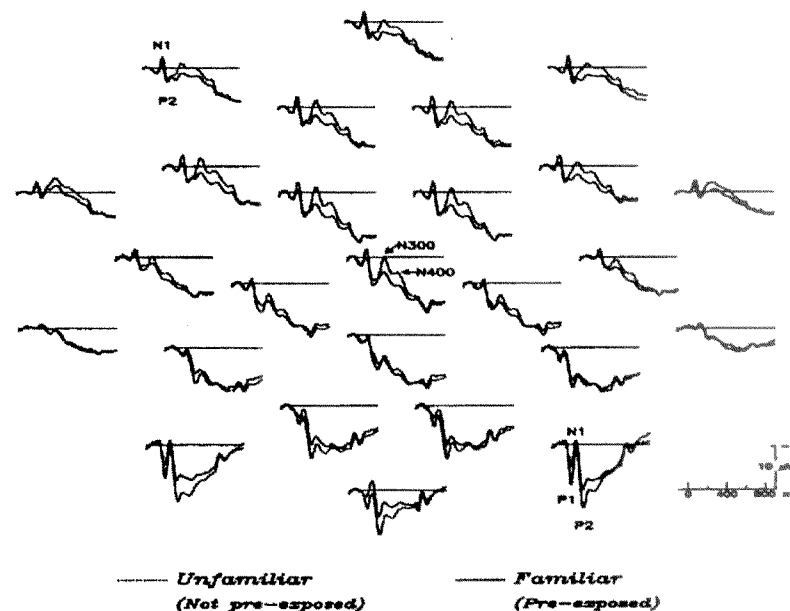


FIG. 11.7.

attentional system (e.g., Clark & Hillyard, 1996; Mangun, Hillyard, & Luck, 1993). Enhanced N1 amplitudes are observed, for example, in response to target stimuli that appear at attended relative to unattended locations in visuospatial selective attention tasks. P2 amplitudes have been linked to processes of visual feature (color, orientation, size) detection, with increased amplitudes generally observed in response to stimuli containing target features (e.g. Hillyard & Muentz, 1984; Luck & Hillyard, 1994).

This familiar vs. unfamiliar comparison also provides the first sign of a remarkably fuzzy border between perceptual and conceptual processes: pre-exposure not only modulated the amplitude of early sensory-evoked and attention-sensitive components but also affected later so-called endogenous components such as the N300 and N400, known to vary with visual-semantic analyses specific to pictures (N300) and to semantic analyses more generally (N400) (see Kutas & Hillyard, 1980; Kutas & Hillyard, 1984; Ganis, Sereno, & Kutas, 1996; McPherson & Holcomb, 1999). These results thus would seem to indicate, perhaps surprisingly, that there are semantic as well as perceptual benefits to pre-exposure. The pre-exposure manipulation thus not only decreased the perceptual load associated with parsing an unfamiliar picture but also ensured that predictions, based on ongoing context, about the semantic features of likely upcoming items could also give rise to relatively accurate predictions (at least as good as participants'

episodic memory based on one exposure) about the nature of the upcoming physical stimulus (as is true for words).

Examining the brain's responses to pictures that participants had seen previously once out of context further revealed that neither semantic congruence (expectancy) nor contextual constraint affected any parameter of the early sensory components evoked by these familiar pictures. By contrast, as anticipated, both these factors did modulate the amplitude of the N300/N400 components of the ERP. Consistent with prior data, the responses to (familiar) contextually congruent pictures (see Fig. 11.8) were characterized by significantly smaller N300/N400 components than those to contextually incongruent pictures. Incongruent pictures (like incongruent words) elicited large negativities between 200 and 600 ms poststimulus onset (N300/N400). And, consonant with the known characterization of the N400 congruency effect, its amplitude varied with contextual constraint, with the largest N400 responses to incongruent items when these were embedded in highly constraining contexts. These results, then, would seem to suggest that early sensory (at least low-level visual) processing, while sensitive to an existing memory trace, is much less subject, if at all, to the match between the ongoing context and/or the constraints it imposes on expectations at a semantic or visuo-semantic level.

This inference, however, must be qualified by the results of this same comparison made with pictures being viewed for the first time (i.e., unfamiliar pictures). In this case, the early sensory visual components of the ERP did show observable sensitivity to both semantic congruence and constraint (see Fig. 11.9). More specifically, the N1 components were reduced

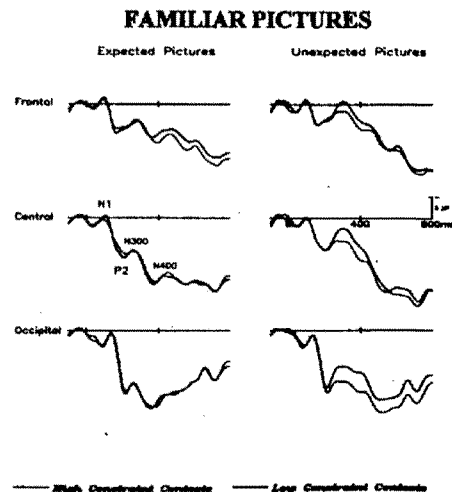


FIG. 11.8.

and P2 components to these same pictures enhanced—i.e., both these early components were relatively more positive when the sentence ending was contextually congruent and highly expected based on the preceding context. These reductions in the amplitude of the N1 and increases in the amplitude of the P2 for expected items in highly constraining contexts as compared with less constraining contexts were apparent in fourteen out of eighteen participants. Top-down information from a strong sentence context thus seems to allow for more efficient allocation of attention (N1) and more efficient extraction of visual feature information and/or reduction of visual processing load (P2). Importantly for the issues at hand, these early, perceptual effects for unfamiliar pictures were correlated with effects on later ERP components (N300/N400) linked to semantic processing. This would seem to indicate that for unfamiliar pictures strong contextual constraint not only eases the semantic processing of expected items, but also provides top-down information that can facilitate visual processing and attentional allocation as needed. The crucial point here is that for picture processing the response to expected endings in highly constraining contexts showed effects of constraint—increased positivity—in several time windows: reduced N1s and enhanced P2s, as well as greater positivity throughout the N300 and N400 time windows of the ERP.

It seems then that, at least under these circumstances, increased ease of perceptual processing and semantic analysis go hand in hand; perhaps the reduced visual processing load in highly constraining contexts frees attentional resources that would ordinarily be used up by perceptual processing to be shifted to conceptual integration processes. In any case, semantic processing is *not* isolated from perceptual factors as domain-specific theories imply. Rather, there seems to be an important link between the ease with which a stimulus can be perceptually deciphered and the nature of the semantic information subsequently derived from the stimulus and available for integration into a sentence context. This finding is especially intriguing given that these same concepts were equally easy to integrate into high as low constraint sentences when they appeared as words instead of picture; in that case, the brain responses to expected endings were unaffected by degree of contextual constraint. In short, for picture processing, there is an apparent link between perceptual and semantic processing that is not observed for word processing with the same sentence contexts and the same concepts. Of course, words as written stimuli are relatively predictable at a visual level as long as the font and size in which they appear in the experiment is fixed; words may thus be much more like familiar than unfamiliar pictures in this regard.

Perhaps somewhat surprisingly, the reduction in the amplitude of the anterior N1 that was observed for unfamiliar pictures when these were expected and embedded in highly constraining contexts was equivalent to

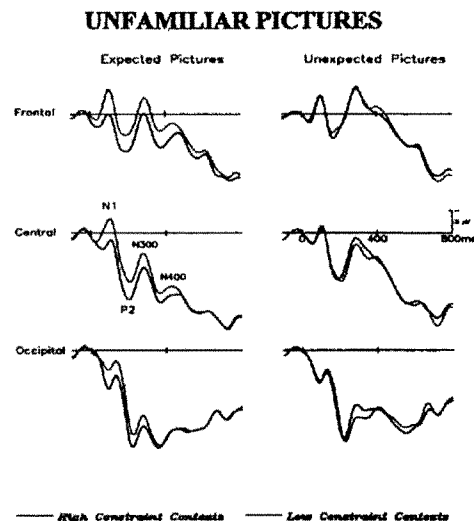


FIG. 11.9.

that for familiar pictures overall. This is an important exception to the finding that the anterior N1 is generally smaller for familiar than unfamiliar pictures. It seems, then, that perceptual difficulty/visual novelty (greater for unfamiliar than familiar pictures) can be offset by top-down information activated from semantic memory from a strong, congruent context. By about 100 ms, bottom-up factors (e.g., perceptual familiarity) and top-down factors (e.g., expectancy for an item based on prior sentence context) seem to come together to affect visual processing.

These data thus suggest that when targets are relatively easy to perceive, as in the case of words and familiar pictures, context has its primary impact on semantic integration processes. In contrast, when visual perception is more difficult (as for pictures being seen for the first time), strong contextual information, as is available in highly constraining contexts, can and does affect processing stages related to allocation of attentional resources and perceptual analysis, as well as later ones related to semantic integration.

When the results of these experiments with pictures are compared with those using words, two conclusions stand out: (1) picture and word processing in sentence contexts elicit quite similar brain responses; and (2) the time course with which pictures and words are integrated into a sentence context seem to be about the same. Thus, in these respects there is nothing domain-specific about how items from these two modalities are processed. It is thus highly unlikely that words and pictures are processed

in completely independent neural systems. That said, there are circumstances under which words and pictures behave differently, and we have evidence (not presented here) that they activate different semantic featural information even in the very same sentence contexts (Federmeier & Kutas, 1999, 2001). From such data we have argued that semantic information exists in a shared distributed system with a modality-specific coding scheme. Our data and conclusions are thus consistent with those who maintain semantic information is distributed over multiple cortical areas that each preferentially process information from a particular modality. In fact, along with others, we have suggested that both hemispheres are involved in semantic (as well as more generally language) processing, although differing in how they make use of semantic information during online sentence processing.

We have examined the nature of the content and organization of semantic knowledge in the two hemispheres because we believe that this has important implications for how each might process language in particular, and make sense of sensory input more generally. We employed the visual half-field technique in normal undergraduates as they read sentences presented one word at a time, with the target (word in some experiments, picture in others) presented randomly two degrees from fixation to the right or left visual field. Here we present the data for the picture version, for exactly the same sentences as in the central vision studies discussed above; in this case, all the pictures were familiar (i.e., one exposure prior to the EEG recording).

ERP responses to pictures presented to the right visual field/left hemisphere (left) and to the left visual field/right hemisphere (right) are shown at two frontal recording sites (Fig. 11.10). With initial picture presentation to either hemisphere, semantic congruency effects were observed on the N400 (dashed boxes) component, just as they had been for lateralized word stimuli. Regardless of presentation hemifield, the ERPs to contextually expected as compared with unexpected pictures are characterized by increased positivity between 250–500 milliseconds, showing that both hemispheres differentiate items that fit the verbal context from those that do not. In fact, the ERPs to expected pictures (as was also true for words) presented in the two visual half-fields did not differ in amplitude, latency or distribution (except for slow, mirror image effects as a function of hemifield seen over medial, posterior electrodes). Semantic integration—sensitivity to semantic congruence—during sentence comprehension, as reflected in the N400, proceeds remarkably similarly in *both* cerebral hemispheres, not just the left as more standard views of language processing have maintained. Picture stimuli also show effects of semantic congruency by 300 ms post-picture onset on the N300 component regardless of visual field of presentation (dotted box), again implying a certain similarity in the two hemispheres' visuo-semantic processing.

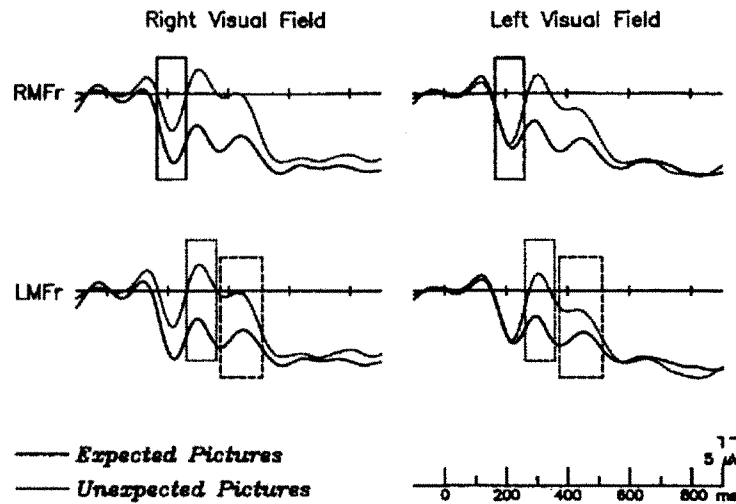


FIG. 11.10.

At the same time the two hemispheres do show some differences in the time course of their sensitivity to congruency effects: overall, the congruency effects appear earlier in the ERP responses initiated by left hemisphere processing. With initial presentation to the left hemisphere, P2 components (solid boxes, between 150–250 ms) are larger to expected than to unexpected pictures. By contrast, P2 components for expected versus unexpected pictures do not differ with presentation to the left visual field. Modulations in P2 amplitude are generally assumed to reflect detection and analysis of basic visual features such as orientation, size, color, etc. Only in the left hemisphere does processing of the individual words in the sentence context seem to provide top-down information allowing for more efficient visual feature extraction from targets (expected items) than from unexpected items. In other words, only with left-hemisphere-initiated processing is top-down contextual information used to prepare for the visual processing of upcoming stimuli. This is consistent with our hypothesis that the left hemisphere (but not the right) uses context to make predictions; importantly, here we see that these predictions can be about perceptual (and not just semantic) features of upcoming stimuli. Again, these results are remarkably similar to what we have seen with regard to the two hemispheres for words. While there are some modality-specific differences between words and pictures that stem from actual differences in the physical nature of the sensory input and the specificity of the semantic information that they render readily accessible, there is nonetheless a remarkable similarity in the timing, polarity, and morphology of semantic ERP responses

for stimuli in the two modalities. Elsewhere we have suggested that pictures activate more specific semantic features than do written or spoken words, and while these influence what semantic information is available, how context is used to anticipate and integrate this information is the same regardless of the modality of the stimulus. Finally, whether for pictures or words, whereas the left hemisphere seems to use context to predict upcoming stimuli and prepare for their processing at semantic and perceptual levels, the right hemisphere's processing of a sentence context seems to provide it with less top-down information.

In sum, we find that an individual's prior experience with a visual stimulus, the fit of that stimulus to a sentence context, the strength of the context, and the hemisphere initiating processing all influence processing at both early and later stages—perceptual and conceptual. The functional specificity of the ERP waveform—including components reflecting sensory processing, feature extraction, allocation of attention, semantic analysis, etc.—has allowed us to see various effects on early ERP components that are correlated with effects on later components, suggesting a strong bidirectional link between perceptual and conceptual processing. Moreover, these effects as well as others are the same regardless of domain—at least for these mechanisms, pictures and words are the same.

Comprehending language involves a number of different kinds of brain processes including perceptual analysis, attention allocation, retrieval of information from long-term memory, storage of information into working memory, and comparisons between/transformations of information contained in working memory. Each of these processes can be examined through an electrophysiological filter—the specific ERP component that indexes a particular functional process. Here we have examined a few of these. But for lack of space, we could have detailed other ERP experiments aimed at examining the others, alone or in various combinations.

CONCLUSIONS

The evidence from normal behavior, neuropsychology, and electrophysiology reported here presents a complex picture of language as a dynamic, multidimensional cognitive system, which is highly dependent upon domain-general processes and resources. The data support an interactive model of language comprehension, in which there is no clear division or unidirectional flow of information between perceptual and conceptual processes. Instead, the evidence reveals that there is transparent information transfer between these levels of analysis, such that variations in the perceptual input directly influence the activation of conceptual information, and that active conceptual information in turn directly influences percep-

tual analysis. Further, both the perceptual properties of the input and the availability of attentional resources play a crucial role in language comprehension. Thus, the disruption of perceptual and attentional processes, either by distortion of the sensory input or by neurological damage, produces predictable patterns of language breakdown in normal and language-impaired individuals, indicating that disorders that have previously been considered to be language-specific may be better accounted for in terms of a domain-general processing account. Finally, the results presented here demonstrate that the neural mechanisms involved in language comprehension are also responsible for the processing of other kinds of information, including the recognition of visual objects, with no evidence for a discrete, dedicated language system.

Considering this evidence in the context of the other chapters presented in this volume, it is striking that for both comprehension and production and for language form and language meaning there is increasing evidence that the type of processing and behavior that is observed is a function, not just of the specific language level engaged or the specific language structure/representation involved, but of a complex interaction between the demands that a particular language places on the system, the demands of the specific task(s) in which the speaker/listener is engaged, and the speaker/listener's current state and prior experience, which together determine the kind and amount of various cognitive resources available to be used. In turn, it is how these resources are brought to bear that will determine the outcome, for a brain-damaged patient, a normal volunteer under stress, or even in a normal volunteer under seemingly routine processing conditions, as reflected in their brain responses. Language is thus special, not in having a dedicated set of cognitive/neural resources to draw upon, but rather in being a cognitive skill/ability that requires such efficient and intricate coordination of so many domain-general abilities, functions, and information sources.

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ADDENDUM

About Liz

When I was finishing my Ph.D. at Brown in 1996, I saw an ad for a postdoc at the Center for Research in Language at UC San Diego, under the supervision of Elizabeth Bates. I was of course very interested in the possibility of working with such an eminent scientist in such a beautiful part of the world, but I had never met Liz, and had no idea what she would be like as a supervisor. A few years earlier I had sat in on Cathy Harris's very enjoyable psycholinguistics course at Boston University, in which she spoke often and fondly of her years as a graduate student at UCSD, so I got in touch with Cathy and asked her whether she thought I should apply for the position. She replied that the only job she might find more appealing than a postdoc in San Diego with Liz would be a position as an officer on the Starship Enterprise under Captain Jean-Luc Picard. I applied for the postdoc immediately.

The following March (to my tremendous good fortune), I packed up my car, left snowy Providence, and moved to San Diego to work with Liz. Thus began one of the most important and formative experiences of my personal and professional life, a story that will be familiar to countless others who have had the opportunity to be a part of life at CRL. On my arrival in San Diego, Liz presented me with a gift: a miniature version of the Mouth of Truth, the statue into which ancient Romans placed their hands and swore to be truthful (lest the mouth close and remove all flesh below the wrist). Liz advised me to consult the statue if I were ever in doubt about the interpretation of my data, and above all else, to let truth prevail. I found that this is a standard she lives by in her own work, and that although she is known for her strong views (an understatement), she is first and foremost a seeker of truth, and a scientist of unfailing integrity. As a supervisor and mentor, Liz is as protective as a mother bear, as well as a relentlessly demanding

critic who challenges her charges to live up to her own high expectations. She generously opens her home to students, postdocs, junior teaching staff, and established scientists, and she has brought about innumerable scientific collaborations (not to mention lifelong friendships and marriages) as a result of the many warm and relaxed gatherings held under her roof. She takes a sincere interest in the professional and personal lives of her students and colleagues, which in my case translated into long walks on the beach at La Jolla Shores, long drinks at sunset in the bar of the Marine Room, and long dinners at Trattoria Acqua overlooking La Jolla Cove, in which we would discuss data, dating, and how to be satisfied with both. Liz is always able to laugh at herself: when she and George decided (with great reluctance) to join a health club, she summed up her experience of the weight room orientation by saying, "Galileo recanted when they showed him *the machines*." She shares her love of all things Italian with anyone who will listen, and those who are fortunate enough to score an invitation to the Bates-Carnevale apartment in Rome receive a crash course in the delights of Trastevere (Averna being my personal favorite). Liz brings her tireless spirit and humor to every aspect of life at CRL, and this has made it less like a research institution than an extended family. I am lucky to have been a part of this family, if only for a short time.

I suppose there is a sense in which I have Cathy Harris to thank for all of this, as it was her recommendation that convinced me to apply to work with Liz in the first place, and for this I am truly grateful. Looking back, I would disagree with Cathy on only one point: if I were back in San Diego with Liz, and I got the call from Captain Picard, I would have to turn him down.

—Jennifer Aydelott
London, September 2003