Reading Words in Discourse: The Modulation of Lexical Priming Effects by Message-Level Context

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Abstract

Repetition and semantic-associative priming effects have been demonstrated for words in nonstructured contexts (i.e., word pairs or lists of words) in numerous behavioral and electrophysiological studies. The processing of a word has thus been shown to benefit from the prior presentation of an identical or associated word in the absence of a constraining context. An examination of such priming effects for words that are embedded within a meaningful discourse context provides information about the interaction of different levels of linguistic analysis. This article reviews behavioral and electrophysiological research that has examined the processing of repeated and associated words in sentence and discourse contexts. It provides examples of the ways in which eye tracking and event-related potentials might be used to further explore priming effects in discourse. The modulation of lexical priming effects by discourse factors suggests the interaction of information at different levels in online language comprehension.

Keywords

words; discourse; eye movement; ERPs; reading

Language is a ubiquitous and arguably unique ability that plays a central role in human cognition and social interaction. The near effortlessness with which we acquire and use language masks its complexity; both language production and comprehension require intricate coordination across disparate levels of knowledge and skill. Simply speaking a sentence aloud involves knowledge of the meanings of words, the arrangement of words into phrases, the sounds associated with words, the physical movements involved in making those sounds, the ways in which different inflections convey different information, and the ways in which social factors can influence the interpretation of speech.

Several characteristics of human language make it difficult to study. In addition to the many levels at which language is structured, language processing is very fast: The different levels of information are integrated online within a very short period of time. During conversational speech, we produce or comprehend 150 to 200 words per minute. Adults of average reading proficiency process 200 to 300 words of text per minute when reading for comprehension. The

remarkable speed at which language is processed demands methods of very high temporal resolution for its investigation. Furthermore, the methods available for studying the neural basis of language are limited by the fact that human language has distinctive characteristics, particularly its creative productivity and extraordinary communicative range, that are not seen in the comparable systems of other species. Consequently, animal models do not exist for core language abilities (but see Hauser, Chomsky, & Fitch, 2002; Jarvis, 2004), and many methods that are used to study the neural basis of other cognitive processes (like perception and memory) cannot be used to study language.

Despite these methodological challenges, language has been central in long-standing debates about the relationship between the mind and the brain. Since the early descriptions by Broca and Wernicke of language deficits that arise from damage to specific parts of the brain, researchers have questioned the extent to which specific language functions can be localized in the cortex (or in subcortical structures). More recently, methods of functional imaging (positron emission tomography [PET] and functional magnetic resonance imaging [fMRI]) have attempted to answer similar questions in brains of neurologically unimpaired individuals. Indeed, some of the first studies to use these methods did so in attempts to localize language functions in the brain (e.g., Petersen, Fox, Posner, Mintun, & Raichle, 1989).

Questions about localization in the brain of component processes of language have become enmeshed in a broader debate about the nature of cognitive processes in general. One view (Fodor, 1983) describes cognitive processing as "modular," in that specialized, autonomous modules are said to be localized in specific parts of the brain. At a cognitive level of analysis, modules are distinguished by the types of information that they process and are said to be informationally encapsulated in that they are not influenced by other types of information. In the case of language, modules might correspond to some of the different levels of representation that are known to affect processing; that is, one might posit a "phonology" module or a "parsing" module, in which the processing of phonological or syntactic information proceeds without influence from other levels of representation. An alternative view is offered by interactive models of cognition (McClelland & Rumelhart, 1988), in which all sources of information are brought to bear on any given computation. On these accounts, there is no expectation that different levels of language analysis will be localized in different brain structures or that mechanisms for language processing will be distinct from those used for processing nonlinguistic information.

One fundamental difference between the modular and interactive accounts concerns the timing of the influence of information from one linguistic level of representation on the processing of another level. Modular accounts propose that processing at one level of representation must be completed before the output of this processing can be combined with information from other processing levels. Interactive accounts, which lack this informational encapsulation, predict the immediate and mutual influence of processing at different levels. Because of the very rapid nature of language processing, methods with high temporal resolution play a very important role in evaluating these distinct claims; methods with suitable temporal resolution include behavioral techniques such as recording eye movements during reading and neurophysiological techniques such as event-related potentials (ERPs). Functional neuroimaging techniques with high spatial resolution but poor temporal resolution (such as fMRI and PET) can provide information about the neural loci of component processes of language but are very limited in their ability to provide information about dynamic aspects of processing.

In this article, we examine the influence of information from different levels of representation on language processing by comparing the comprehension of words presented in a linguistically structured context with words presented in isolation. More often than not, the words that one

attempts to comprehend are embedded within the context of a meaningful sentence or a structured discourse. The comprehension of a sentence or a discourse involves such processes as syntactic parsing (Frazier, 1987; Frazier & Rayner, 1982), the assignment of thematic roles (Carlson & Tanenhaus, 1988; Clifton, Speer, & Abney, 1991), the establishment of reference and coreference (Gernsbacher, 1989; Gordon & Hendrick, 1997; McKoon & Ratcliff, 1980), the generation of inferences (Graesser, Singer, & Trabasso, 1994; Haviland & Clark, 1974; Singer, Andrusiak, Reisdorf, & Black, 1992; Singer & Ferreira, 1983), and the evaluation of meaning in terms of context and real-world knowledge (Hagoort, Hald, Bastiaansen, & Petersson, 2004; Jackendoff, 2003). Thus, the comprehension of a sentence or a discourse involves processing beyond that of the component words, processing that integrates lexical information with contextual knowledge and extralinguistic information to allow a reader or a listener to derive a message-level meaning. Here, we review two well-established and consistently demonstrated lexical priming effects: repetition priming and semantic association priming. These effects are known to arise when words with a certain relationship to each other (either being identical or sharing semantic features) are presented together in isolation or in a word list. We then review behavioral and electrophysiological evidence of the modulation of such effects by sentential or discourse context.

This review focuses on research measuring eye movements during reading and ERPs to study the influence of context on lexical repetition and semantic association priming effects. Evidence from these complementary methods permits examination of how the sentence- and discourse-level contexts interact with, and in some cases override, basic memory processes involved in processing words. Eye tracking during reading provides a sensitive measure of the timing of the input to language comprehension as it occurs when participants have strategic control over reading. It provides an online behavioral measure of language comprehension with fine-grained temporal resolution under relatively natural circumstances. ERPs can be obtained for spoken and written language and provide a continuous neural measure that can tap into these language processes as they unfold in real time. ERPs provide information with very fine temporal resolution about the neural processing induced by stimuli. Because separable ERP components are sensitive to separable aspects of language processing (e.g., semantics vs. syntax), they can give a direct indication of the component mechanisms of language comprehension processes. The effects of repetition priming and semantic priming have been investigated in functional neuroimaging studies as well; generally, these studies have shown reduced activation (especially in temporal and frontal regions) to target words that are preceded by identical or semantically associated words (see, e.g., Buckner, Koutstaal, Schacter, & Rosen, 2000; Copland et al., 2003; Dehaene et al., 2001; Gabrieli et al., 1996; Giesbrecht, Camblin, & Swaab, 2004; Kotz, Cappa, von Cramon, & Friederici, 2002; Matsumoto, Iidaka, Haneda, Okada, & Sadato, 2005; Rissman, Eliassen, & Blumstein, 2003; Rossell, Price, & Nobre, 2003; Wible et al., in press). However, because of our interest in understanding the timing of the interaction of lexical and discourse factors in language comprehension, and because of the relatively poor temporal resolution of functional neuroimaging methods, this review focuses on the higher temporal resolution methods of eye tracking and ERPs (and their relation to more traditional behavioral results).

In reviewing results using these methods, we first turn our attention to the nature of word repetition effects and how they are modulated by context. We then turn our attention to the way in which semantic association affects word comprehension and to how those priming effects are modulated by context.

LEXICAL REPETITION EFFECTS

Behavioral Evidence

Repetition priming is the facilitation of lexical processing observed on second and subsequent presentations of a word. Generally, a target word is processed more quickly and more accurately when preceded by an identity prime, an earlier presentation of itself. Scarborough, Cortese, and Scarborough (1977) demonstrated immediate and delayed repetition priming effects in lexical decision and naming tasks. Since that time, such effects have been observed in a variety of experimental paradigms. Repetition priming is generally stronger when the prime and the target are presented within the same modality, although cross-modal repetition priming has been demonstrated (Grainger, Diependaele, Spinelli, Ferrand, & Farioli, 2003; Marlsen-Wilson, Tyler, Waksler, & Older, 1994). Although repetition priming is strongest when the target immediately follows the prime, the processing benefit has been shown to persist across extended periods of time (lags) between prime and target presentation (Scarborough et al., 1977).

Most models of repetition priming propose that the first presentation of a word leads to some change in the cognitive system that affects processing on the second presentation of the word. However, there is a great deal of debate about the exact nature of this change to the cognitive system. One view (the abstractionist view; Carr et al., 1994; Tenpenny, 1995) localizes the change to abstract knowledge structures, such as the logogen (a word's corresponding unit in the mental lexicon; Morton, 1969). According to this view, the initial presentation of a word results in changes in the activation level of the logogen; at the time of the second presentation of the word, this residual activation can decrease the overall additional activation needed to reach the logogen's threshold, resulting in facilitated processing. An alternative view (the episodic view; Levy & Burns, 1990; Masson, 1995; Tenpenny, 1995) describes repetition priming as arising from memory of prior episodes in which an item was encountered. These views lead to differing predictions about the effects of factors such as modality of presentation and experimental task, which have been supported to varying degrees across a large number of experiments (see Tenpenny, 1995, for a review).

Electrophysiological Evidence

The effect of lexical repetition in word lists has been linked most strongly to two ERP components, the N400 and the late positive complex (LPC).

The N400 is a negative deflection in the ERP waveform that peaks approximately 400 ms poststimulus onset and is maximal over posterior electrode sites. Evidence from intracranial recordings (McCarthy, Nobre, Bentin, & Spencer, 1995; Nobre & McCarthy, 1995) and high-density ERP recordings (Johnson & Hamm, 2000) indicate participation of the anterior temporal lobes in the generation of the N400 component. A reduction of the amplitude of the N400 is found for words that can be easily integrated into the preceding word, sentence, or discourse context; this component is thus sensitive to processes of lexical integration (e.g., Brown & Hagoort, 1993; Chwilla, Brown, & Hagoort, 1995; Holcomb, 1993; Rugg, Furda, & Lorist, 1988; van Berkum, Hagoort, & Brown, 1999; Van Petten & Kutas, 1991). Lexical repetition leads to a reduction of the N400 component (Bentin & Peled, 1990; Joyce, Paller, Schwartz, & Kutas, 1999; Rugg, Doyle, & Melan, 1993). This reduction has been shown to persist across lags; however, the effect is greatest at shortest lags (Nagy & Rugg, 1989). The N400 repetition effect has been observed across a variety of tasks, including lexical decision (Bentin & Peled, 1990; Karayanidis, Andrews, Ward, & McConaghy, 1991; Rugg et al., 1988), semantic classification (Hamberger & Friedman, 1992; Rugg et al., 1988), and recognition memory tasks (Bentin & Peled, 1990). It has also been observed in cross-modal studies of repetition priming (Domalski, Smith, & Halgren, 1991; Holcomb, Anderson, &

Grainger, 2005; Joyce et al., 1999; Rugg et al., 1993). The effect is restricted to repeated items that are semantically meaningful; geometric line drawings, for example, do not show a reduced negativity in the N400 time range as a result of repetition (Rugg, Soardi, & Doyle, 1995; Van Petten & Senkfor, 1996).

The LPC is a positive-deflecting component that begins approximately 400 ms poststimulus onset and can continue until 900 ms. It is also maximal over posterior electrode sites and is sensitive to explicit recall. Lexical repetition in word lists leads to an increase in the amplitude of the LPC (Paller & Kutas, 1992; Paller, Kutas, & McIsaac, 1995; Rugg, 1985, 1990; Swick & Knight, 1997). The increase of the LPC for repeated words in lists (relative to nonrepeated controls) has been linked to the explicit recall of the prior presentation (Paller et al., 1995). Specifically, several researchers have suggested that the LPC might index the recollection component (but not necessarily the familiarity component) of the dual-process model (Jacoby & Dallas, 1981).

In summary, repetition priming has been demonstrated robustly with words outside of a linguistically structured context, using a number of behavioral measures. Repetition has been shown in several studies to affect at least two ERP components: Repetition leads to a reduction of the N400 and an amplification of the LPC.

Before turning to a review of the effects of lexical repetition in sentence and discourse contexts, it is worth mentioning a study in which repeated words were embedded in a minimal context created by the simultaneous presentation of two words on each trial (Rugg, Doyle, & Holdstock, 1994). Words were repeated in the same local context (presented with the same word as previously) or in a changed local context (paired with a different word). Rugg et al. (1994) argued that if ERP effects of repetition reflected an increased ease of integration with context, then repeated words in the same context should elicit greater repetition effects than repeated words in changed contexts. Contrary to this prediction, Rugg et al. found equivalent N400s and LPCs to repeated words in same and changed contexts; they concluded that the repetition effect was not sensitive to local context.

LEXICAL REPETITION IN SENTENCE AND DISCOURSE CONTEXTS

Behavioral Evidence

Several behavioral studies have been designed to examine priming effects when repeated words are embedded in sentence or discourse contexts. Carr, Brown, and Charalambous (1989) found that discourse context did not interact with lexical repetition in reading times. Their first experiment presented congruent and scrambled paragraphs twice; the second presentation either matched the first in presentation form or was in the alternate form. Participants were asked to read the paragraphs aloud. Reading times showed evidence of repetition priming in that paragraphs were read more quickly on second presentation. However, the magnitude of priming was not influenced by the contextual similarity between the first and second presentation. Carr et al. (1989) concluded that the properties of the context in which repeated words are found were relatively unimportant in determining repetition priming.

Bainbridge, Lewandowsky, and Kirsner (1993) came to a different conclusion. In their stimuli, they repeated target words that had few or many meanings or senses (defined by the number of distinct entries listed in the dictionary) in one of three different sentence context conditions: the same context as an earlier presentation, a different context that maintained the same sense, or a different context that demanded a different sense of the target word. Repetition priming (as assessed by lexical decisions to the target words) was reduced if the repeated word was presented in a context that required a different sense interpretation than the initial presentation.

Words that maintained the same sense across different contexts elicited priming comparable to words that were presented in the same context.

Several studies using eye tracking during reading have demonstrated a text-repetition effect or rereading benefit, in which a text is read more quickly on subsequent presentations than on the first (Raney, 2003; Raney, Therriault, & Minkoff, 2000). These studies differ from those presented later in this section in that it is the entire text that is repeated from one presentation to the next. The results of text repetition studies may differ from the other studies, then, in important ways. First, in text repetition research, the relevant integration is between the repeated word and earlier portions of the repeated text, not with the earlier instance of the repeated word as it is in other studies of repetition priming in context. Also, the critical repeated words have greater separation in text repetition research than in other sentential stimuli, and those words are surrounded by other repeated words.

However, there does seem to be at least one similarity between the results of text repetition studies and the results of eye-tracking studies that focus more specifically on lexical repetition (see below), and that similarity has to do with a dissociation in the temporal locus of different effects. In text repetition studies, early eye fixation measures (which are typically associated with processes of lexical access) are often influenced by lexical repetition alone. Later eye-tracking measures (which are typically associated with processes of integration) may be influenced by lexical repetition but also are influenced by more integrative processes, in which semantic and other influences can have an effect. For example, in Raney et al. (2000), lexical access alone was taken to be indicated by fixation duration when a word was fixated only once, whereas integration plus lexical access were taken to be indicated by the sum of fixation durations when a word was fixated more than once. Exact lexical repetition led to shorter fixation times for instances of both single fixations and multiple fixations, whereas synonym repetition led to shorter times only in cases of multiple fixations.

A handful of studies have used eye tracking to examine the modulation of lexical repetition effects by sentential context. Traxler, Foss, Seely, Kaup, and Morris (2000; Experiment 2) contrasted lexical repetition and sentence plausibility. As can be seen in Example 1, the critical word (italicized in the example) either repeated the word used as the sentential subject (in 1a and 1c) or did not (1b and 1d). Sentence plausibility was derived from the integration of the critical word with the preceding sentential context; someone greeting a lumberjack is plausible (1a and 1b) but someone chopping a lumberjack is not (1c and 1d).

> 1a. The lumberjack greeted the *lumberjack* early this morning.
>
> 1b. The young man greeted the *lumberjack* early this morning.
>
> 1c. The lumberjack chopped the *lumberjack* early this morning.
>
> 1d. The young man chopped the *lumberjack* early this morning.

As described above for text repetition studies, eye-tracking measures in this experiment were differentially sensitive to these two manipulations. First fixation duration and gaze duration measures showed a repetition priming effect, with shorter times for repeated than for new critical words. On the other hand, total reading time showed a main effect of plausibility. In other words, early measures were sensitive to repetition priming, whereas later measures were sensitive to sentential context.

In another study of lexical repetition effects in sentence contexts, Liversedge, Pickering, Clayes, and Branigan (2003) measured eye movements during the reading of adjunct phrases for which thematic role assignment (temporal or locative) was temporarily ambiguous. As shown in Example 2, target sentences (containing the ambiguous adjunct) were preceded by a context sentence that biased a temporal or a locative thematic role assignment.

2a. Locative/locative

Context: The maid thought about where to peel/prepare the vegetables.

Target: In fact, she peeled them in the kitchen, with great care.

2b. Locative/temporal

Context: The maid thought about where to peel/prepare the vegetables.

Target: In fact, she peeled them in the morning, with great care.

2c. Temporal/locative

Context: The maid thought about when to peel/prepare the vegetables.

Target: In fact, she peeled them in the kitchen, with great care.

2d. Temporal/temporal

Context: The maid thought about when to peel/prepare the vegetables.

Target: In fact, she peeled them in the morning, with great care.

To differentiate between two hypotheses about the locus of the thematic biasing effect, verbs were repeated (or not) across context and target sentences. Liversedge et al., reported a main effect of verb repetition for first-pass reading time of the region following the verb region (*in the* in the example). Shorter reading times for congruent contexts than incongruent contexts were found for the two regions following the disambiguating noun (the spillover region [*with great*] and the final region [*care*]). These congruency effects emerged most strongly in the aggregate measure of total reading time and in the later measure of rereading, again suggesting a dissociation between repetition priming effects (which tend to influence early processing measures) and context effects (which tend to influence later processing measures).

In summary, then, behavioral results using oral reading times and lexical decision have shown mixed effects of sentential context on repetition priming. In eye-tracking studies of text repetition and of lexical repetition in sentence contexts, early measures of reading have shown effects of repetition priming, whereas later measures of reading have shown effects of sentential context.

Electrophysiological Evidence

Several studies have examined lexical repetition effects for words that are embedded in meaningful sentence or discourse contexts using ERPs; the results have demonstrated that the electrophysiological signature of such words may differ from that seen to repeated words in lists. In Besson, Kutas, and Van Petten (1992), highly constrained sentences that ended with either an expected terminal word or an anomalous terminal word were presented twice to participants. Participants were asked to read the sentences for comprehension and to attempt to memorize the final word. After each block of sentences, participants were given a cued recall test in which they were asked to provide the terminal word of each sentence that had appeared in that block when given the other words of the sentence. Behavioral results showed a benefit of repetition; congruous and incongruous words were recalled more frequently when they had been repeated. Repetitions of the highly expected congruous terminal words did not show a reduction of the N400, but this may have been due to a floor effect (in that the first presentation of these words elicited only a small N400 response). Repetitions of these words did elicit a smaller LPC. The ERPs to repeated incongruous terminal words looked like those to repeated words in lists, with a reduction of the amplitude of the N400 and an increase of the amplitude of the LPC.

Besson and Kutas (1993) looked at repeated words that were presented in the same or a different context on the second presentation. Sentences ended in a critical terminal word that was low in cloze probability, defined as the proportion of participants who will choose a particular word as being the most likely completion of a sentence fragment. In the same word/same context condition, participants saw the same sentence twice. In the same word/different context condition, the sentence final word was repeated across the two presentations, but the context changed (*She found some good mushrooms* vs. *She did not like mushrooms*). In the different word/same context condition, the sentence context was maintained but a new terminal word was presented (*I have met him in this museum* vs. *I have met him in this bar*). Also included was a different word/different context condition, in which neither context nor the terminal word was repeated. Participants in this experiment were asked to read silently for comprehension and to memorize the final word of each sentence for a later memory test. As in the Besson et al. (1992) experiment, the cued-recall test asked participants to fill in the missing terminal word when presented with the experimental items. The largest reductions in N400 amplitude, and the best behavioral performance on the cued-recall test, were seen in the same context/same word condition. The repetition of sentence context was crucial to lexical repetition benefits.

In the same study, Besson and Kutas (1993) also looked at the repetition of homographs (words that are spelled the same but have different meanings) in four context conditions: the same context and the same meaning of the homograph (the entire sentence was repeated), a different context but one that biased the same meaning of the homograph (*The bicycle mechanic replaced the spoke* vs. *He cut his hand on the spoke*), a different context that biased a different meaning of the word (*The losing gambler asked for a new deck* vs. *The sailor was ordered to scrub the deck*), or a different context with a different word. As with the nonhomographs, they found repetition effects only for the homographs that were repeated in the same context; changing the sentence context effectively eliminated the repetition benefit.

The inclusion of an explicit memory task in the two studies described above may have led to different processing strategies on the part of readers in those experiments (see Gordon, Hendrick, & Ledoux-Foster, 2000). Van Petten, Kutas, Kluender, Mitchiner, and McIsaac (1991) attempted to avoid this possibility by asking participants to read short, naturalistic nonfiction texts taken from the *Reader's Digest*. The use of repeated words was not uncommon in these texts and allowed an examination of repetition priming in a discourse context. Repetitions of both content words and proper names resulted in N400 amplitude reductions similar to those seen to words in lists. Repetitions of these two types of words, however, differed in their LPC response. The LPC to proper names was more positive with repetition but was reduced to repeated content words. Van Petten et al. (1991) reasoned that the LPC to words in discourse might act as a marker of retrieval and updating demands in working memory. Proper names initially introduce people who are unknown to the reader and therefore are unlikely to elicit extensive memory retrieval and updating processes on first presentation. On subsequent presentation of proper names (which were often separated from their initial presentations by several intervening sentences), comprehension does require the reinstatement of the prior memory representation and its updating by new discourse information. On the other hand, content words require the greatest retrieval and updating processing on first presentation; to the extent that lexical representations activated during this initial presentation are still active at the time of repetition, retrieval processes are facilitated. The reduction of the LPC to repeated content words in context and the increase of the LPC to repeated proper names in context may thus reflect the differential engagement by these two types of words in processes of memory reinstatement and updating. It is unclear from these data, however, what types of processes are being engaged in interpreting the repeated names. Because it was only after a referent had been out of discourse focus for some time that a name was repeated, these instances are better thought of as cases of reinstatement (O'Brien, Albrecht, Hakala, & Rizella, 1995) rather than local coreference, a topic to which we turn next.

One important function of repeated words in natural discourse is the establishment of coreference, in which two words are taken to refer to the same semantic entity. In coreference, the first expression (the antecedent) introduces an entity into the discourse model, and the second expression (the anaphor) refers to it. Coreference can occur both within and between sentences and can be established by the use of full expressions (such as descriptions or names) as well as reduced expressions (such as pronouns and ellipses); it is a fundamental mechanism for making language coherent (Grosz, Joshi, & Weinstein, 1995; Kintsch & van Dijk, 1978). A recent study by Anderson and Holcomb (2005) examined lexical priming effects and discourse coreference effects during sentence processing. Participants read two-sentence passages like that seen in Example 3:

3. First sentence:

> Kathy sat nervously in the *cab/taxi* on her way to the airport.

Second sentence:

> *The cab* came very close to hitting the car.

> *A cab* came very close to hitting the car.

Repetition priming was assessed at the critical noun in the second sentence (*cab*) that was either a repetition of a word in the first sentence or a synonymous word. Coreference was manipulated by the use of *the* or *a* before the critical noun; the use of the definite noun phrase (NP) *the* encourages a coreferential interpretation, whereas the use of the indefinite NP *a* does not. Anderson and Holcomb (2005) found N400 priming effects at the critical word for both repetitions and synonyms; consistent with previous studies, repetition priming effects were greater than semantic priming effects. Neither repetition nor synonymy had an effect on the LPC. There was no evidence of a main effect of coreference on the N400, nor was there an interaction of the repetition and coreference factors.

ERP studies of lexical repetition in sentence and discourse contexts, then, have shown some results that are inconsistent with those demonstrated for words in lists or other nonstructured contexts. Most studies have demonstrated N400 repetition priming effects for words in context. When an explicit memory task was included and participants were asked to recall the sentence final words, lexical repetition effects (and cued-recall repetition priming effects) were dependent on the repetition of sentence context. Other studies have shown N400 lexical repetition effects without repetition of the sentence context. The effect of repetition on the LPC to words in a sentence or a discourse has been more variable, with some studies finding an increase in the amplitude of this component, some finding a decrease, and others finding no significant change at all. Some of these changes may reflect differences in the retrieval and updating demands made by different types of words (Van Petten et al., 1991).

Lexical Repetition and Coreference

We have used predictions from a model of coreferential processing to derive predictions about the modulation of repetition priming effects in discourse. Gordon and Hendrick's (1998) discourse prominence theory specifically addresses the processes involved in establishing coreference with repeated names in a sentence or in a discourse. According to their model, the primary function of names is to introduce entities into the discourse model. Coreference with repeated names results in the introduction into the discourse model of two entities predicated on the same name and therefore may require additional mental processes to integrate the two entities (as is necessary to achieve a coreferential interpretation). The ease of establishing coreference between two instances of the same name in a sentence will be influenced by discourse factors such as the linguistic prominence of the antecedent, which can be manipulated, for example, by its depth of embedding: An antecedent that is the singular subject

of a NP is more prominent in the discourse representation than one that is embedded in a conjoined NP (Albrecht & Clifton, 1998; Gordon & Hendrick, 1997, 1998; Gordon, Hendrick, Ledoux, & Yang, 1999). A coferentially repeated name will be processed less easily when it follows a more prominent antecedent than when it follows a less prominent one. In such cases of repeated name coreference to a linguistically prominent entity, discourse prominence theory suggests that for an initial period of time, the second instance of the name is treated as a new name; subsequently, the processes for establishing equivalence between the two instances will result in their integration but with a resultant processing cost. The cost that arises when a repeated name corefers with a prominent antecedent, termed the *repeated name penalty*, has been demonstrated in self-paced reading studies (Almor, 1999; Garrod, Freudenthal, & Boyle, 1994; Gordon, Grosz, & Gilliom, 1993; Gordon et al., 1999; Kennison & Gordon, 1997; Yang, Gordon, Hendrick, & Hue, 2003).

Swaab, Camblin, and Gordon (2004) provided electrophysiological evidence of the difficulty of establishing coreferential relations between two names when the first instance of the name is presented in a prominent sentential position. Participants read sentences like those presented in Example 4:

4a. Pam washed the dishes while Pam talked about politics.

4b. Pam and Joe washed the dishes while Pam talked about politics.

In this example, the first instance of *Pam* is more prominent in 4a than in 4b; in 4b, the name is presented as part of a conjoined NP, and linguistic focus is drawn to the conjoined subject (and not its component members). We compared the N400 response to the repeated name in the two conditions and found a reduction of the N400 to repeated names that were preceded by a nonprominent referent, relative to those preceded by a prominent referent. Because the N400 is sensitive to difficulties in lexical integration, this difference suggests that the difficulty of achieving coreference with a name increased with the prominence of the referent.

We were unable in this experiment, however, to directly assess lexical repetition effects because we used pronouns as a comparison for the repeated names. Although this allowed a test of theoretical notions about the centrality of pronominal reference in discourse coherence, the fundamental lexical differences between names and pronouns (along such dimensions as word frequency, length, and word class) made comparison between pronouns and names difficult.

In a later set of experiments, using eye tracking and ERPs with the same stimuli, we used noncoreferential new names to directly measure lexical repetition effects and coreferential processes during reading (Ledoux, Gordon, Camblin, & Swaab, in press). Participants read sentences like those presented in Example 5.

5a. Prominent NP1/repeated name

At the office *Daniel* moved the cabinet because **Daniel** needed room for the desk.

5b. Prominent NP1/new name

At the office *Daniel* moved the cabinet because **Robert** needed room for the desk.

5c. Nonprominent NP1/repeated name

At the office *Daniel and Amanda* moved the cabinet because **Daniel** needed room for the desk.

5d. Nonprominent NP1/new name

At the office *Daniel and Amanda* moved the cabinet because **Robert** needed room for the desk.

In these sentences, prominence of the first name in the sentence (the first instance of *Daniel* in the example, italicized) was manipulated by whether it was the sentential subject in a singular first NP (the prominent condition) or was embedded in a sentential subject consisting of a conjoined NP (the nonprominent condition); prominence is inversely related to depth of syntactic embedding (Gordon & Hendrick, 1998). The subject of the second clause was realized as a repeated name matching the first name in NP1 (the second *Daniel* in 5a and 5c, in bold) or as a new name (*Robert* in 5b and 5d, in bold).

To the extent that repetition effects are immune to the influence of higher level processing, we might expect to see evidence of repetition priming regardless of the structural constraints of the sentence. In this case, we would expect to see a processing benefit for a repeated word, relative to a new word, in conditions that are otherwise identical (in 5a vs. 5b and in 5c vs. 5d). The predictions of discourse prominence theory, on the other hand, suggest that readers will be subject to a specific influence of discourse context. According to discourse prominence theory, coreference will be easily and readily established using repeated names when the antecedent is not prominent in the discourse model (5c); in such sentences, the benefits of repetition and ease of integration will conspire to facilitate processing. When the antecedent is more prominent in the discourse model (5a), however, repeated name coreference will be difficult. The facilitation of processing that is conferred due to repetition might in such cases be countered by a relative difficulty of integration due to the structural constraints of the sentence. Discourse prominence theory, then, leads to a prediction of the modulation of repetition priming in conditions in which prominence inhibits the establishment of coreference.

We found support for this prediction in both the eye-tracking and ERP experiments (Ledoux et al., in press). In the eye-tracking experiment, in line with previous experiments examining text repetition and lexical repetition in context, we found a dissociation of the lexical repetition effects and the discourse prominence effects. At the critical name, we found main effects of repetition (shorter reading times for repeated than new names) on first fixation and gaze duration measures. This difference persisted to some extent in later measures (i.e., rereading) and comprehensive measures (i.e., total reading time) of processing. For the spillover region following the critical name (the verb of the second clause), we found no significant effects on the early processing measures. We did, however, find an interaction between type of name (repeated or new) and type of NP1 (prominent or nonprominent) on later processing measures: For total reading time and for rereading, for repeated names, times were shorter when the subject of the first clause was a conjoined NP as compared to when it was a singular NP; for new names, times in these conditions showed the reverse. For early processing measures (and persisting to some extent to later ones) at the critical name, we found robust evidence of repetition priming. For later processing measures at the spillover region following the critical name, we found a modulation of these repetition priming effects: Repeated names were processed more quickly than new names were, but only when the first instance of the name was not linguistically prominent in the discourse representation. When the first instance of the name was linguistically prominent, we found a reversal of repetition priming effects. The difficulty of integrating a coreferentially repeated name with a linguistically prominent antecedent outweighed the benefit normally conferred by lexical repetition (at least in later processing measures).

Similar support for the predictions of discourse prominence theory of the modulations of lexical repetition effects by discourse context came from an ERP experiment using the same materials. In the N400 time window (250-500 ms), we found an interaction of type of name (repeated or new) and type of NP1 (singular/prominent or conjoined/nonprominent). Pairwise comparisons showed N400 repetition priming effects for the conjoined condition but not for the singular condition; that is, when the first instance of the name was prominent in the discourse representation, there was no difference in the amplitude of the N400 to repeated and new names.

The comparison by discourse condition showed that whereas our new name controls did not differ when they followed a prominent versus a nonprominent first NP, our repeated names did differ significantly, with a reduced N400 to repeated names that followed a nonprominent (relative to a prominent) NP1. This electrophysiological example of the repeated-name penalty attests to the difficulty of integrating a coreferentially repeated name with a prominent antecedent. Finally, we did not find a modulation of the LPC to the critical words as a function of repetition. We did find a difference for the repeated names by discourse condition; repeated names that followed a nonprominent antecedent elicited a greater positivity in the LPC window than did the same repeated names when they followed a prominent antecedent. If the LPC reflects retrieval and updating processes, it seems that repeated names initiate these processes to a greater degree following a conjoined (relative to a singular) sentential subject. This may reflect the imposition of a greater memory load by the conjoined NP1, which requires greater subsequent engagement of processes of retrieval and updating.

In summary, in two experiments, one using eye tracking and the other using ERPs, we found a modulation of repetition priming effects by discourse context. The predictions of the discourse prominence theory (Gordon & Hendrick, 1998) were borne out, in that the benefits of repetition were modulated in sentences in which that repetition was used to create coreference between a name anaphor and a linguistically prominent antecedent.

LEXICAL SEMANTIC ASSOCIATION EFFECTS

Behavioral Evidence

William James wrote that words could be activated by other words: "Each word is *doubly* awakened; once from without by the lips of the talker, but already before that from within by the premonitory processes irradiating from the previous words" (1890, as quoted by Foss, 1982). Semantic associative priming is the facilitation of lexical processing conferred by having recently processed another semantically related word. Target words that are preceded by related prime words are processed more quickly and more accurately than are targets that are preceded by unrelated prime words. Meyer and Schvaneveldt (1971) demonstrated this effect using a lexical decision task. For letter string pairs that were presented simultaneously, reaction times were faster if two words were primary associates (*bread-butter*) than if they were unrelated (*doctor-butter*). Using the same simultaneous presentation technique, Fischler (1977) showed a priming effect for words that were semantically, but not associatively, related (*nurse-wife*). Subsequent studies have suggested that effects of "pure" semantic priming may be smaller than effects of associative priming (see Lucas, 2000, for a review).

Several mechanisms have been proposed to account for relatedness priming effects. Neely (1991) provided an excellent review of relevant relatedness priming data from lexical decision and naming experiments and reviewed three theoretical mechanisms for semantic priming. (Neely and Keefe, 1989, proposed a hybrid three-process theory in which all of these mechanisms play a role in determining semantic priming effects.) One mechanism by which priming might occur is through the automatic spreading of activation (ASA) between lexical nodes in a semantic network. That is, processing the prime word results in the activation of the prime's corresponding lexical node. This activation automatically spreads to the lexical nodes of semantically related words. If the target has already been activated to some degree by this ASA, upon its presentation, it will take less time to reach the recognition threshold level of activation than if the prime had not been processed (and activation had not spread). This mechanism is considered both automatic (in that it happens without conscious control) and prelexical (in that the priming benefit arises before the target word's lexical node has been accessed).

A second mechanism discussed by Neely (1991) is expectancy-based priming. According to this explanation, some aspects of semantic priming effects may arise due to expectations that are developed by participants in response to the prime word. In other words, participants may use the prime word to develop a set of potential targets that are expected to follow. These expectations, if correct, can speed the processing of the target upon its presentation. Like ASA, expectancy-based priming is considered prelexical, in that it operates before lexical access of the target has occurred; unlike ASA, however, expectancy-based priming is considered to be under conscious control.

Finally, Neely (1991) reviewed a set of proposed priming mechanisms that are thought to operate after the lexical node of the target has been accessed and are thus considered to be postlexical priming mechanisms. One example is Neely and Keefe's (1989) semantic matching hypothesis, which was proposed to explain some of the priming effects found with the lexical decision task. Semantic matching occurs after lexical access for the target has occurred, when participants use semantic relatedness information to speed their word/nonword response. According to Neely and Keefe's (1989) reasoning, only words in the experiment lead to judgments of semantic relatedness; nonword targets are designed to avoid activation of real words that are semantically related to their prime. Participants can thus use the presence of semantic relatedness as a cue to "wordness" and the absence of semantic relatedness as a cue to "nonwordness." In this way, semantic relatedness can lead to speeded reaction times in the lexical decision task. Such an account depends on strategic processing by participants and thus would be considered controlled.

The effects of relatedness priming have been robust across a variety of paradigms. Associatively and semantically related word pairs have been shown to benefit from intralexical priming (although there may be quantitative or qualitative differences between the facilitation produced by these relation types). Several mechanisms have been proposed to explain the nature of these priming effects.

Electrophysiological Evidence

Bentin, McCarthy, and Wood (1985) were the first to demonstrate evidence of associative priming using ERPs. They had participants perform a lexical decision task in which approximately one third of the target words were immediately preceded by a prime from the same semantic category (e.g., *tulip-lilac*). Behaviorally, lexical decision reaction times were faster for targets that had been preceded by a category prime. Electrophysiologically, associative priming effects were observed as a reduction in the amplitude of the N400 to primed targets, relative to words that had not been primed.

Subsequent studies have shown N400 associative priming effects in the auditory modality as well (Anderson & Holcomb, 1995; Holcomb & Neville, 1990). In addition, the N400 is sensitive to semantic associative priming across auditory and visual modalities (Holcomb & Anderson, 1993). The N400 relatedness priming effects are not restricted to the presentation of words; semantically related pictures also show a decrease in N400 amplitude (although with a somewhat more frontal distribution than the canonical N400 effect found with words; Barrett & Rugg, 1990; McPherson & Holcomb, 1999).

Several ERP studies have varied aspects of the experimental design with the goal of emphasizing reliance on prelexical versus postlexical priming mechanisms or automatic versus controlled mechanisms. For example, Kutas and Hillyard (1989) had participants perform a letter detection task in which they responded whether a presented letter had been seen in the two serially presented previous words. The N400 to target words that had been preceded by an associated prime word was reduced relative to targets that had been preceded by an unrelated word. Because priming was not relevant to the participants' behavioral task, Kutas and Hillyard

reasoned that the N400 priming effects must reflect automatic processes. On the other hand, Holcomb (1988) demonstrated an influence of the proportion of related words used in the experiment (a factor that had been previously related to controlled processing mechanisms; Neely, 1977) on the magnitude of N400 priming effects. Other studies have implemented manipulations of other variables thought to differentially demand the engagement of automatic or controlled processes in an attempt to better understand semantic associative priming (Chwilla, Kolk, & Mulder, 2000; Deacon, Hewitt, & Tamny, 1998; Holcomb, 1993; Weisbrod et al., 1999).

Several of these experiments have had implications for our understanding of the processing nature of the N400 component. For example, Brown and Hagoort (1993) studied the effects of using masked primes in a lexical decision task. Behaviorally, they found evidence of relatedness priming; interestingly, however, they did not find a modulation of the N400 by relatedness. Because masked priming is generally taken to reflect ASA from an (unconsciously perceived) prime to a target, this result was interpreted as evidence that the N400 is not sensitive to such automatic mechanisms. Recently, others using the masked priming paradigm have come to a different conclusion; for example, Deacon, Hewitt, Yang, and Nagata (2000) found similar attenuation of the N400 to semantically related targets following masked and unmasked primes and concluded that the N400 is indeed sensitive to processes of automatic lexical activation, at least in some priming paradigms.

In summary, then, relatedness priming has been shown to decrease the amplitude of the N400 component of ERPs. Although there is agreement that the N400 is sensitive to controlled semantic matching and semantic integration processes, there is a great deal of debate over its sensitivity to automatic mechanisms such as ASA.

LEXICAL SEMANTIC ASSOCIATION EFFECTS IN SENTENCE AND DISCOURSE CONTEXTS

Behavioral Evidence

A number of studies over the past several decades have demonstrated semantic associative priming effects for words in sentence contexts. In Kleiman (1980), participants read high-cloze sentences that were missing their terminal word; they were then presented with a target word to which they made a lexical decision. Three different kinds of target words were used: the best completion to the sentence, words that were associated with the best completion word, or words that were not associated with the best completion word. In addition to a main effect of congruity (with words that created a congruous ending to the sentence showing faster reaction times), Kleiman reported evidence of the priming of the best completion word by the sentence context. Interestingly, even when this word was not presented, facilitated processing of an associated word was seen, suggesting that relatedness priming effects can emerge even when an expected prime is not actually presented. Blank and Foss (1978) used a slightly different experimental paradigm to examine context effects on relatedness priming. Using a target phoneme-monitoring task, they found that the processing of a word in a sentence was facilitated when a semantically related word preceded it. Carroll and Slowiaczek (1986) found evidence of relatedness priming in sentences using eye tracking; they reported shorter first fixation durations for words that had been preceded in a sentence by a related word.

These results could be accommodated within a model in which lexical automatic spreading of activation is the mechanism by which priming occurs (a lexical-lexical activation explanation; Foss & Ross, 1983). An alternative model was developed by Duffy, Henderson, and Morris (1989), in which a slightly greater role was given to the power of sentential context. According to their combination model, target words that might not otherwise be activated by individual

words could be activated by a combination of words. Duffy et al. used rapid serial visual presentation (RSVP; in which words are presented centrally one word at a time in succession at relatively fast rates) to display sentences such as *The barber trimmed the mustache*, in which the final word (which remained on the screen until a response was made) was the critical target for naming. Neither of the content words prior to the critical word (*barber* and *trimmed*) was strongly related to the target (although both were weakly related). Naming times for the target words were facilitated by the inclusion of both weakly associated words in the sentence, relative to sentences that included just one of the words or contained only neutral words. After eliminating attentional or integrative explanations in subsequent experiments, Duffy et al. concluded that the priming of sentence terminal words was not due to message-level processing but to the automatic combination of content words within the lexicon. Morris (1994) used similar materials in a follow-up eye-tracking study. She also found evidence of priming (as measured by reductions in first fixation duration) for sentences in which both weakly associated content words were presented. However, in her second experiment, in which she manipulated the semantic relationship between the subject and the verb (in sentences such as *The gardener talked as the barber trimmed the mustache after lunch* vs. *The gardener talked to the barber and trimmed the mustache after lunch*), facilitation was found for the critical word only when the message-level representation of the context supported the target word (even though the same content words were used in the sentences in both conditions). This result stands in contrast to that found by Duffy et al. (1989) using a similar manipulation. Two eye-tracking studies in Morris and Folk (1998) also showed evidence of message-level context effects in sentences in which syntactically marked focus was manipulated.

These last eye-tracking studies, along with a number of other studies, rendered the lexical-lexical activation explanation and the combination model of Duffy et al. (1989) less plausible. Using a paradigm similar to that of Blank and Foss (1978), Foss (1982) showed facilitated processing of associated words in sentences but not in word lists (which consisted in this experiment of scrambled versions of the sentences) when 12 words separated the prime and the target. The magnitude of the priming effect in these sentences was the same as that observed in sentences in which the prime and target were separated only by 1.5 words. O'Seaghdha (1989) also found relatedness priming effects for words embedded in sentence phrases that were syntactically sound but not for words in scrambled phrases; Simpson, Peterson, Casteel, and Burgess (1989) found a similar result.

Foss (1982) interpreted these results as being due to processes that are unique to the construction in memory of a discourse model and the active maintenance of discourse-relevant information. Words in lists do not benefit from such maintenance, and activation decays over a delay, to the extent that it is no longer available at the target to facilitate lexical access if enough words intervene. Priming in context, then, is seen to arise from mechanisms that are outside of the lexicon and is determined primarily by the activation of elements that are relevant to the discourse (for additional discourse-based perspectives, see Auble & Franks, 1983; Foss & Ross, 1983; Foss & Speer, 1991; Hess, Foss, & Carroll, 1995; N. E. Sharkey, 1990; A. J. Sharkey & Sharkey, 1992).

Foss and colleagues tested this hypothesis in experiments in which they orthogonally manipulated local and global context. Local context consisted of the word prior to the target word; this word's relationship to the target could be associatively or semantically related or not. Global context was established by the general topic of the discourse in which the sentence containing the critical word was embedded. Foss and Speer (1991), using a phoneme-monitoring task, found that semantic associative priming depended not on the local context but on the global context; in fact, when the critical word was related to the global context, processing was facilitated to the same extent for locally associated and locally unassociated words. Hess et al. (1995), using a similar design, auditorily presented sentences within a

discourse context; the critical terminal word of the final sentence of each discourse was presented visually for naming. The terminal word was preceded in the sentence by an associated or unassociated agent/verb phrase. Thus, local context (related or unrelated) was established by the pairing of the critical word with the agent/verb phrase, whereas global context (related or unrelated) was established by the pairing of the critical word with the overall discourse topic; the two factors were orthogonally manipulated. Naming times showed effects of global relatedness (with words named more quickly following a related discourse than an unrelated one); local relatedness had no effect. This is especially interesting given that associative priming effects were found in their baseline experiment (Experiment 1) for the same critical words in the same sentence fragments when the fragments were presented in isolation (and thus global context was removed). Hess et al. (1995) argued that a discourse-based model of priming effects best accounted for their data.

Traxler et al. (2000) tested three different explanations of the ease of integration of some words into certain contexts: intralexical automatic spreading activation accounts, schema accounts (in which priming may occur due to the increased activation of schema components once a schema is activated), and situation model accounts (which are similar to the discourse-based models described above). Their second experiment, which involved a manipulation of lexical repetition, was described in the preceding section on behavioral effects of repetition priming in context. In their first experiment, they used a 2×2 factorial design to manipulate schematic relatedness and sentence plausibility in stimuli like those presented in Example 6.

> 6a. The lumberjack carried the *axe* early in the morning.
>
> 6b. The young man carried the *axe* early in the morning.
>
> 6c. The lumberjack chopped the *axe* early in the morning.
>
> 6d. The young man chopped the *axe* early in the morning.

In 6a and 6c, the target word (*axe*, italicized in the example) is preceded by an associated word (*lumberjack*); in 6b and 6d, it is not. In 6c and 6d, the target word, when encountered and integrated with the sentence context, renders the sentence implausible; 6a and 6b are plausible continuations. Traxler et al. reasoned that main effects of association would support an intralexical ASA model; main effects of plausibility would support a situation/discourse model account. According to a schema account, activation of the schema should lead to priming of schema-related words, even if the sentence is implausible (though perhaps to a lesser degree in this case). Such an account might be supported by an interaction of the two factors (with greater priming in plausible sentences but priming nonetheless in the associated/implausible condition). No effects were observed on early processing measures (first fixation duration or gaze duration), and only a main effect of plausibility was observed on total reading time. This result was taken to support the situation/discourse model accounts.

In their third experiment, Traxler et al. (2000) replaced the associated words of Experiment 1 with synonyms (e.g., *The minister/lawyer greeted /inflated the <u>pastor</u> yesterday at the post office*). Main effects of plausibility (with shorter times for plausible sentences than implausible sentences) were observed on first fixation duration and total reading time measures, indicating an effect of context on both early and late processing measures. Thus, across the two experiments (and in Experiment 2 using lexical repetition and plausibility), effects of context were observed in the absence of associative or synonymous priming effects (only lexical repetition priming was observed).

In summary, although some studies have demonstrated lexical associative priming for related words in sentence or discourse contexts, several others have shown a modulation of these lexical effects by the message-level context. Situation/discourse model accounts of these priming effects, in which priming occurs as a result of processes of discourse representation

in memory, seem to provide better accounts of the existing priming data than lexical-lexical activation or combination accounts.

Electrophysiological Evidence

Van Petten (1993) used ERPs to examine semantic associative priming for word pairs that were embedded in congruent or anomalous texts; an example of the four conditions created by crossing lexical association and sentence congruity is shown in Example 7.

7a. When the *moon* is full it is hard to see many *stars* or the Milky Way.

7b. When the *insurance* investigators found that he'd been drinking they *refused* to pay the claim.

7c. When the *moon* is rusted it is available to buy many *stars* or the Santa Ana.

7d. When the *insurance* supplies explained that he'd been complaining they *refused* to speak the keys.

Significant N400 priming effects were found in the associated/congruent condition (7a), the unassociated/congruent condition (7b), and the associated/anomalous condition (7c). The priming effect in 7b can be attributed to the sentential context; the priming effect in 7c can be attributed to lexical association. The priming effect in 7a was significantly larger than that seen in the other two conditions (7b and 7c), suggesting additive effects of the two types of context (lexical and sentential) on priming. In addition, Van Petten (1993) reported substantial individual variability in the magnitude of the sentential priming effect. In fact, the magnitude of the sentential priming effect correlated with behavioral performance on a memory probe word task used in the experiment (an effect not observed for lexical associative priming). Van Petten, Weckerly, McIsaac, and Kutas (1997) followed up on this finding of individual differences in sensitivity to context effects using the same stimuli (and a faster presentation rate). Participants were divided into groups with low, medium, or high memory span based on their performance on the reading span task (Daneman & Carpenter, 1980). All three groups showed evidence of lexical associative priming (in anomalous sentence contexts). The medium and high span groups showed a main effect of sentence context on priming, with reduced N400s to the critical word in congruent relative to anomalous sentences. The low span group, however, showed evidence of a sentential context priming benefit only when associated words were present in the sentence; in the unassociated condition, no difference was seen in the N400 to the critical word in congruent and anomalous sentences for this group. Van Petten et al. (1997) concluded that the availability of working memory resources is an essential constraint on the ability to benefit from sentence-level (but not necessarily lexical-level) context.

Van Petten et al. (1999) orthogonally manipulated lexical association and sentence congruency in sentences like those seen in Example 8.

8a. When someone has a heart attack a few minutes can make the difference between *life* and *death*.

8b. The gory details of what he had done convinced everyone that he deserved *life* in *prison*.

8c. The gory details of what he had done convinced everyone that he deserved *life* in *death*.

8d. When someone has a heart attack a few minutes can make the difference between *life* and *prison*.

In this 2 × 2 design, lexical-level context was manipulated by the use of associated (*life-death*) and unassociated (*life-prison*) word pairs. Sentence-level context was manipulated by

the use of congruent (8a and 8b) and incongruent (8c and 8d) sentences. Preliminary testing demonstrated behavioral and electrophysiological priming effects for the associated (relative to the unassociated) word pairs when they were not embedded in the sentence context; that is, lexical decision reaction times were faster and N400 amplitudes were reduced for associated words. When the words were embedded in congruent and incongruent sentence contexts, however, these effects of lexical association disappeared. Instead, a main effect of sentence congruity (with reduced amplitude to congruous vs. incongruous sentences) was seen on the N400. The only effect of association was seen on the amplitude of the LPC, with a larger positive shift to associated terminal words in incongruous sentence contexts, an effect that was taken to reflect the realization of conflict between sentential and associative context.

In a subsequent study, Coulson, Federmeier, Van Petten, and Kutas (2005) examined hemispheric differences in processing association and sentence congruence using the same stimuli. In this experiment, they presented the stimuli using a visual half-field paradigm, in which each word of the sentence is presented centrally (using RSVP), except the final word, which is presented laterally to one visual field (counterbalanced across participants). As in the Van Petten et al. (1999) study with central presentation, presentation to both hemispheres in this experiment showed a robust congruity effect. Small, spatially restricted effects of association were also observed, with association producing a canonical N400 effect only for incongruent words presented in the left visual field.

The experiments described so far in this section used sentences that were in general highly constraining. Participants were likely to have developed predictions about upcoming words, predictions that may have been violated by the use of a different word in conditions in which this was necessary for the orthogonal manipulation of association. The N400 has been shown to be sensitive to cloze probability: Its amplitude is inversely correlated with cloze probability or expectedness (Kutas & Hillyard, 1984). This factor may have been confounded to some extent with congruency in the previously reviewed studies. For example, in the Van Petten et al. (1999) study, sentence frames were matched for cloze probability in the associated-congruent and unassociated-congruent conditions, with mean cloze probability in both conditions being very high (about 71%). Because the same frames were used in the incongruent conditions, the manipulation of the critical word for the purposes of association rendered the sentences incongruent but also led to the violation of an expectation. It is possible, then, that effects of association might reemerge in stimuli that were less constraining. Hoeks, Stowe, and Doedens (2004) presented evidence in support of this interpretation. Participants read sentences in which message-level constraint and schematic relatedness were manipulated. They found evidence of effects of both message-level constraint and intralexical, schematic relationships on immediate lexical processing. When sentences contained words that were schematically associated, no difference was found in N400 amplitude to terminal words that were highly expected (e.g., *The javelin was by the athletes thrown*) and words that were anomalous in the context (e.g., *The javelin has the athletes thrown*). It was only when the terminal word did not benefit from schematic relatedness that effects of message-level constraint emerged on the N400. As in the study by Van Petten et al. (1999), a larger positivity followed the N400 for the incongruent words that were lexically primed.

In summary, the results of several studies have demonstrated the modulation of lexical associative priming effects by sentence-level context. The exact interaction of these factors may depend to some extent on the level of constraint imposed by the sentence context. In highly constraining contexts, associative priming effects may be greatly attenuated or overridden. In less constraining contexts, association may have a stronger effect, particularly on the processing of incongruent words.

Lexical Semantic Association and Discourse Congruency

The experiments presented above addressed the question of whether lexical associative priming effects are modulated by sentence context. We explored a related issue, that of the interaction of lexical-level effects and effects that arise from the creation of a meaningful representation at the level of a discourse. In a series of ERP and eye-tracking experiments, we investigated the reading of passages in which lexical association and discourse congruence were manipulated (Camblin, Gordon, & Swaab, in press). Associated and unassociated words were embedded in sentences that were coherent and locally congruent and identical across conditions. The critical words were either congruous or incongruous with the discourse-level context that emerged from the integration of meaning across the sentences of the passage. An example of the stimuli used in the experiments is presented in Example 9.

> 9a. Associated/congruent
>
> > Lynn had gotten a sunburn at the beach. Nothing she tried would help her dry and irritated skin.
> >
> > Lynn couldn't stop scratching her *arms* and *legs*.
>
> 9b. Unassociated/congruent
>
> > Lynn had gotten a sunburn at the beach. Nothing she tried would help her dry and irritated skin.
> >
> > Lynn couldn't stop scratching her *arms* and *nose*.
>
> 9c. Associated/incongruent
>
> > Lynn's wool sweater was uncomfortable and itchy. She fidgeted as the rough material irritated her skin.
> >
> > Lynn couldn't stop scratching her *arms* and *legs*.
>
> 9d. Unassociated/incongruent
>
> > Lynn's wool sweater was uncomfortable and itchy. She fidgeted as the rough material irritated her skin.
> >
> > Lynn couldn't stop scratching her *arms* and *nose*.

A cloze pretest indicated that the stories on average were only moderately constraining, thus reducing the role of expectancy and possibly allowing more robust effects of associative priming to emerge (if in fact such effects have been partially obscured in previous studies by expectancy).

These stimuli were first tested in an ERP experiment, in which the signal was time locked to the sentence terminal word. The first two sentences were presented all at once for the participants to read at their own pace, but, as is common in ERP research, the final sentence was presented one word at a time at a pace of 500 ms per word. We found a main effect of discourse congruence on the amplitude of the N400, with a reduction of the amplitude of this component seen to words that were congruent with the discourse-level context relative to words that rendered the discourse incongruent. That this effect emerged early (in fact, earlier than the canonical N400 effect, as early as 150 to 250 ms after the onset of the critical word) suggests an immediate influence of discourse-level meaning on the processing of the critical word. In addition to its early emergence, this effect lingered beyond the typical N400 time window, with differences observed for congruent versus incongruent words in the late 500- to 900-ms window. We also observed effects of association; however, here, the pattern differed from that seen for congruence. The N400 effect (with a reduction seen to associated relative to unassociated words) emerged later than that of congruence (in the 300- to 500-ms window).

And although we found a difference by association in the 500- to 900-ms LPC time window (with unassociated words eliciting a greater positivity than associated words), this effect emerged only in the incongruent discourse condition. We thus found evidence of the rapid use of discourse congruence and a comparatively delayed effect of association in the processing of words in text.

The time course of interlexical and discourse effects was also tested using eye tracking (Camblin et al., in press; Experiment 2). A subset of the stimuli from the ERP study was used, and for these passages, a final sentence was added so that reading measures could be assessed for a target and posttarget window. Here, there was some evidence of an early effect of association producing shorter gaze duration and regression path reading times in the target region. However, these effects were not robust, proving significant only in the subject analyses and not the item analyses. On the other hand, discourse congruence had robust effects on regression path duration and rereading in both the target and posttarget region.

Because eye-tracking measures to sentence final words are known to reflect some processing related to sentential wrap-up effects (Rayner, Sereno, Morris, Schmauder, & Clifton, 1989), we conducted another set of eye-tracking experiments in which we added text to the third sentence of each passage after the critical word. If effects of association were being clouded by sentential wrap-up, the use of midsentence targets should allow these effects to emerge. In addition, previous studies of eye tracking (Rayner, Warren, Juhasz, & Liversedge, 2004) have also suggested that effects of discourse congruence might be delayed for midsentence targets, a possibility that could now be examined with these new materials.

As expected, these midsentence targets in Experiment 3 did show a more delayed effect of congruence: Main effects of discourse congruence (with more time spent reading incongruous than congruous words) were observed on gaze duration and regression-path duration measures of the posttarget region only. Only in rereading measures did we see evidence of the effect of congruence on the target region (as well as on the posttarget region). For the target region, an effect of association was observed on regression-path duration and rereading durations, but this effect interacted with discourse congruence such that associative priming was only observed for incongruent discourse passages. Effects of association that did not interact with congruence were not found until the posttarget window, in which associated words produced shorter regression-path durations and rereading times.

In subsequent eye-tracking experiments, we further explored the influence of a discourse model on associative priming. In Experiment 4, we presented the same target sentences in isolation and found very early effects of association affecting skipping rates and all first-pass reading measures in the target region. Then, to ensure that the modulation of associative priming effects by discourse context that we observed was not due simply to a length-of-passage effect, we conducted another eye-tracking experiment (Camblin et al., in press; Experiment 5), in which the congruence manipulation was replaced by a discourse cohesion manipulation. Passages identical to those used in the congruous condition of Experiment 3 were used here in the cohesive condition; scrambled passages, created by mixing up the sentences used in different passages, were used in the noncohesive condition. Association was manipulated as in the previous experiments. We found an interaction of association and passage coherence, in that associative priming effects emerged on early measures of target processing but only in the scrambled texts, where it elicited shorter first fixations and gaze durations.

In summary, effects of discourse congruence were robust in both eye movement measures and ERPs; discourse incongruent words were more difficult to process, even though they were congruous at the sentence level and even when they were associated with a previous word in the sentence. Discourse congruence affected the ERP in all time windows tested and affected

first-pass measures in the eye-tracking studies in which this factor was manipulated. In contrast, association had a more malleable effect. When measured with ERPs, effects of association that were not modulated by congruence were found only in the N400 time window. When measured with eye tracking, the earliest effects were found for word pairs embedded in isolated sentences where associated words were skipped more often than unassociated words. When a scrambled discourse context was available, these effects were only slightly delayed, emerging first for first fixation measures. Effects were delayed even further when these words appeared in a cohesive discourse context in which the critical word itself did not fit with the discourse model, eliciting shorter regression path durations for associated words. Finally, when these words were congruous with the cohesive discourse model created by the passage, robust association effects were either delayed into the posttarget region or they did not appear at all. It seems, then, that as more information becomes available for the development of a discourse model, the effects of association become increasingly delayed. Thus, when a cohesive, congruent discourse model can be constructed, this global model may override bottom-up associative facilitation.

DISCUSSION

Lexical priming effects have been demonstrated for repeated words and for semantically associated words when presented in environments with minimal linguistic structure (word pairs or lists of words). Behaviorally, these priming effects are evidenced as facilitated processing in a number of different tasks and under different presentation conditions. Electrophysiologically, effects of both repetition and semantic association are seen on the N400 component of the ERP, the amplitude of which is reduced to target words that are preceded by an identical or associated prime word. In addition, priming may have an effect on the LPC to words in pairs or in lists.

When repeated or semantically associated words are embedded in a meaningful sentence or discourse context, there is greater vulnerability in lexical priming effects than is observed in less structured contexts. This is less true of repetition priming than it is of semantic priming. Behavioral studies of words in repeated texts have shown that lexical repetition priming effects can be observed even when words are embedded in a meaningful context (as long as that context does not demand a different interpretation of the word's meaning). Eye-tracking studies of repeated words in sentences have shown a persistence of repetition priming effects in these contexts; these priming effects tend to emerge in early processing measures and may be replaced in later processing measures by effects of sentential or discourse context. ERP studies have demonstrated N400 repetition priming effects to repeated words in sentences; in some studies, in which explicit memory demands were high, these effects depended on the repetition of sentence context. The effect of repetition on the LPC to words in context has been more variable, and some studies have reported finding no effect on this component at all. In our own experiments, in which we manipulated lexical repetition and the discourse factor of prominence, we found evidence of the modulation of repetition priming effects by discourse context (Ledoux et al., in press). Similar to previous experiments using eye tracking, repetition priming effects were observed on early processing measures (first fixation duration and gaze duration), but the modulation of these effects by message-level context appeared in later processing measures (total reading time and rereading). In the ERP experiment, we found a modulation of N400 repetition priming effects by discourse context, such that clear repetition priming was observed only when the discourse context supported the use of repeated names.

Behavioral studies of semantically associated words in meaningful contexts have shown mixed results; although some studies have demonstrated lexical associative priming for related words in context, several others have shown a modulation of these effects by context. Similar mixed results are seen in eye-tracking studies, with some studies reporting evidence of associative priming even in sentence contexts and others reporting modulation of these effects by context.

ERP studies, on the other hand, have quite consistently demonstrated evidence of the modulation of lexical associative priming effects by sentence-level context. In these studies, message-level context effects seem to be most influential in determining the processing of a given word; it is only when the context is less constrained, or possibly when the critical word is incongruent with the context, that effects of association to any degree emerge. In our own experiments using associated words that were congruous or incongruous in their discourse context, we found robust effects of message-level context and weaker, more variable effects of association (Camblin et al., in press). In the ERP experiment, discourse context influenced the amplitude of the N400 earlier and for a longer period of time than did lexical association. Effects of association on the LPC were observed only when the associated word rendered the discourse incongruous. In an eye-tracking experiment, we found early, robust associative priming effects when associated words were embedded in cohesive sentences or in those same sentences when they were part of an incoherent discourse (in which message-level meaning could not influence comprehension). In stark contrast, when the locally congruous sentences in which the associated words were embedded were presented as part of a meaningful discourse, in which the critical word was manipulated to be in line with or at odds with the message-level meaning, we found robust effects of the discourse context on eye-tracking measures. When effects of lexical association were observed, they were smaller than the effects of discourse context and were observed primarily on later processing measures.

One factor that seems to influence the magnitude of priming effects observed in sentence contexts is the relationship between a repeated or associated word and its context. When repeated or associated words are used felicitously in context, lexical priming effects seem to emerge. When, on the other hand, the repeated or associated words are used infelicitously, in a way that is contradictory to the message-level interpretation, modulation of the priming effects is observed. For example, Carroll and Slowiaczek (1986) and Duffy et al. (1989) reported evidence of associative priming in early eye-tracking measures (first fixation duration) in contexts in which association and message-level context were not at odds. Traxler et al. (2000), on the other hand, found no evidence of associative priming in their measures of eye tracking and instead found main effects of sentence context when lexical association and sentence plausibility were varied orthogonally.

In our own work studying the effects of lexical repetition and association in context, we have designed our materials so that the extraction of a message-level interpretation may be at odds with lexical priming mechanisms. In our repetition experiments, we used the predictions of discourse prominence theory (Gordon & Hendrick, 1998) to develop a situation in which the use of a repeated name would (at least temporarily) hinder the construction of a coherent discourse representation. In our association experiments, we manipulated association and discourse-level congruence orthogonally, such that the two mechanisms of lexical priming and discourse comprehension would sometimes contradict each other.

In both cases, we found evidence that processes that operate in the service of creating a coherent discourse model have at least as great an effect on the processing of a given word as do more lexically specific processes. In our repetition experiments, we found an advantage in eye-tracking and ERP measures of repeated words over new words, as long as this repetition did not impede the construction of a discourse representation. In cases in which repetition was at odds with processes of coreference (when the antecedent of a repeated name was prominent in the discourse representation), the advantage for repeated names over new names was reduced (affecting only early processing measures in the eye-tracking experiment) or eliminated (with similar N400 amplitudes to repeated and new names in the ERP experiment). In our association experiments, we found evidence of semantic associative priming effects, again, as long as this association did not impede the construction of a coherent message-level interpretation of the discourse. In cases in which a cohesive, congruent discourse representation could be

constructed during reading, effects of lexical association were delayed and in some cases overridden.

These results suggest an early influence of information from one linguistic level of representation on the processing of another level; that is, processes that are engaged in the service of extracting the meaning of a discourse may interact with processes that are engaged during the comprehension of individual words, and this interaction may occur very early in time. These results are more easily accommodated within an interactive model of language processing, in which a role is posited for the immediate and mutual influence of processing at different levels of linguistic analysis.

Both eye tracking and ERPs offer high-resolution temporal information about cognitive processing during language comprehension. In general, in our own experiments, the two methods have yielded similar conclusions about the modulation of lexical priming effects by discourse context. However, there are some important differences. For example, in the repetition experiment, we observed a dissociation between early and late eye-tracking measures that was not evident in the ERP results. These differences may be related to differences in the experimental tasks used in the two paradigms. One important difference between eye tracking and ERP paradigms is the method of presentation and the resultant duration of stimulus exposure. Research with eye tracking has shown that when presented with natural, coherent text and asked to read for comprehension, participants spend an average of approximately 250 ms on each word. Although the time spent processing a given word varies widely (perhaps the most basic premise of eye-tracking research is that this variability reflects differential engagement of cognitive processes), it would be highly unusual for participants to spend up to 500 ms on each and every word in a stimulus sentence. In our ERP paradigm, on the other hand, we presented stimuli using RSVP, with one word displayed every 500 ms. These two aspects of the ERP experimental design—the fact that words are presented one at a time and at a potentially slower than normal reading rate—have led some to suggest that the reading processes tapped by ERP research may not be "natural"; reading may be hindered to some extent by the word-at-a-time presentation but may be facilitated to some extent by the possibility afforded by the long presentation duration of the engagement of attentional or other reading strategies. However, those studies that have used auditory versions of the same experimental stimuli used in visual experiments (using RSVP at slow presentation rates) have shown similar effects of experimental manipulations (see, e.g., van Berkum et al., 1999; van Berkum, Zwitserlood, Hagoort, & Brown, 2003). We recently conducted an ERP experiment using auditory presentation of the stimuli from our repetition experiment and found exactly the same modulation of repetition priming effects by our discourse manipulation (Camblin, Ledoux, Boudewyn, Gordon, & Swaab, in press).

What other differences, then, exist between eye-tracking and ERP experimental paradigms? One important difference may be that of the ability in eye tracking (but not in ERP) experiments to move backward and forward in text at one's will. Certainly, regressive eye movements have been shown to reflect difficulties in processing; participants tend to return to parts of a text that created a comprehension difficulty (Rayner, 1978, 1998). In addition, a great deal of evidence suggests that participants begin processing a given word before they fixate directly on that word. Such parafoveal preview benefits can decrease the fixation time of any given word (Rayner, 1978, 1998). Indeed, recent models of eye movements during reading describe processing as distributed in nature, in that a given fixation on a word might reflect the simultaneous contributions from the processing of the previous, current, and subsequent words (Reichle, Pollatsek, Fisher, & Rayner, 1998). Thus, readers' natural processing goals (e.g., abstracting more information from some words or parts of a text or skipping words or parts of a text for which parafoveal processing has been sufficient) are evidenced to some extent in the

pattern of forward and regressive movements in eye tracking. Such goals may be thwarted in the RSVP paradigm, and reading processes may be necessarily adjusted under such situations.

Whereas the research discussed in this review has contributed to our understanding of the moment in time at which the wider discourse influences or maybe even changes lexical processing, no clues have yet been provided as to which brain circuits may be involved in this process. Previous work with brain-damaged, language-impaired patients and with non-brain-damaged individuals using functional neuroimaging have provided some evidence that temporal and inferior frontal cortices are differentially engaged by the processing of words within and outside of meaningful context (Dronkers, Wilkins, Van Valin, Redfern, & Jaeger, 2004; Friederici, 2002; Hagoort, 2005). In our own work, patients with lesions that include inferior frontal cortex but who demonstrate relatively intact comprehension show normal associative and semantic N400 priming effects (Hagoort, Brown, & Swaab, 1996). However, these patients show electrophysiological evidence of a delay in the integration of the contextually appropriate meaning of ambiguous words in sentence contexts (Swaab, Brown, & Hagoort, 1998). Relative to normal control subjects, they additionally showed delayed N400 effects of discourse congruency (Britz & Swaab, 2005). These results indicate that global discourse is not integrated as rapidly in patients with lesions that include inferior frontal cortex. Functional neuroimaging studies that have examined meaning integration in context have also consistently shown involvement of the inferior frontal cortex (e.g., Hagoort et al., 2004). Future studies of the brain circuitry of language comprehension could further contribute to our understanding of the representation of the message-level context in the brain and its interaction with other types of linguistic representations.

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