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Word Perception and Misperception in Context

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When reading lists of words and nonwords at 100 ms/word, Ss reported words accurately but frequently converted nonwords such as *dack* into similarly spelled words such as *duck* or *deck*. In sentences, both nonwords and anomalous words were misread as appropriate words, but the bias was greater for nonwords. Word associations in lists (e.g., *sailor–dack–vessel*) produced a similar bias, but when sentence meaning was pitted against such associations the lexical effect was largely overridden. Sentences in which biasing context appeared only after the critical item reduced but did not eliminate the context effect, suggesting that multiple word candidates remained active while at least the next 3 words were processed. These results support a 2-stage modular interactive model: The first stage is stimulus driven and emits multiple weighted candidates that are combined interactively with contextual information in a second stage.

In reading or listening to discourse, up to five or six words may be perceived and understood per second: a remarkable cognitive feat. Although one might think that processing language simultaneously at several levels—discriminating letters or phonemes, identifying words, parsing and interpreting sentences, and constructing a representation of the discourse—would be more difficult than focusing attention on just the lowest one or two levels, the opposite has been shown to be the case. In general, letter perception is more accurate when the letters are embedded in words (the word superiority effect, Reicher, 1969; Wheeler, 1970; see Estes & Brunn, 1987, for a recent reconsideration), and word perception is more accurate when the words are embedded in sentences (e.g., for speech; Miller, Heise, & Lichten, 1951). Yet the detailed mechanisms underlying the positive effects of higher level context on word perception have been a matter of theoretical and experimental debate since the earliest days of experimental psychology.

The debate centers on the way in which sensory-driven, bottom-up processing is combined with background knowledge. Everyone agrees that by the time a listener or reader has reached a final interpretation of a word, sentence, or text, both lower level and higher level knowledge will have been taken into account. The issue is when, during processing, various sorts of knowledge become available. In the present study, the question is how sentence context influences the identification of a word (or wordlike letter string) in a sentence. Three broad types of models are considered: modular, interactive, and modular interactive.

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Modular Models

In models such as the type proposed by Fodor (1983, 1985), word perception takes place in an autonomous module that combines sensory input with only a restricted class of background information: a listing of words in the lexicon and perhaps their frequency and recency. The perceptual module outputs a word, normally the correct word, which is passed on to the next module, the context integrator. This module is responsible for integrating the word into the sentence. (The integrator includes the parser and semantic interpreter, which may themselves be modular.) Readers or listeners only become aware of the selected word after the context integrator has incorporated the word, if all goes well.

If no word is emitted by the perceptual module, if the emitted word cannot be successfully integrated into the sentence, or if the resulting sentence appears to express an anomalous idea, the reader becomes aware that there is a problem. At this point, he or she may adopt any of several strategies for solving the problem, including reconsidering the identity of one or more words in the sentence. Sentence context and other background information may be used freely to figure out what the word is.

This version of the modular model fails to account for the well-established effects of single-word and sentential context on early, non-conscious stages of word processing (e.g., Meyer & Schvaneveldt, 1971; see Balota, 1990, for a review). Hence, Forster (1979), Fodor (1983), and others proposed a modification of the strong modular model that we term the *lexical-priming modular model*. According to this model, the frequent co-occurrence of two words in discourse creates associations between their lexical entries in the word-perception module. As a result, a stimulus word not only activates its own entry but also primes associated entries. The functional justification proposed for such an arrangement is that it sensitizes the perceptual module to words likely to appear in a given context, but it does so in a computationally simple way that preserves processing modularity.

Interactive Processing Models

Theorists such as Morton (1969), Massaro (1979), and McClelland (1987; McClelland & Rumelhart, 1981) have proposed an interactionist architecture in which sensory, lexical, and contextual information are jointly used to determine what word is perceived, before awareness. Although the details of these interactionist models differ in important ways, particularly with respect to whether there is feedback from higher to lower levels or only convergence of the various sources of information at a given level (see McClelland, 1991, for a recent discussion), all share the idea that the quality of the information from each source is taken into account in determining the perceptual outcome. That is, the stronger the sensory evidence for a word, the weaker the influence of sentence context, and vice versa.

In an interactive model, initial stimulus processing of a word generates degrees of evidence for and against each of a large number of possible words (in effect, all the words in the lexicon). In parallel, information from the sentence context generates evidence for and against words. The output of this interactive process is the one candidate with the highest level of activation (or the one that passes a given threshold of activation first). If no candidate emerges, then the problem is likely to become conscious, and general problem-solving strategies will be brought into play, as in modular models.

Modular Interactive Models

The strength of modular models of word perception is that they separate early perceptual processes that analyze letter shapes and word patterns from parsing and higher level cognitive processes that access knowledge about how the world works and what is a plausible chain of ideas. The kinds of information needed for the early and later processes are so radically different that, on a priori grounds, one would argue that they should be handled by different processors. However, the weakness of such models is that they have difficulty accounting for the ubiquitous, sensitive, and unconscious use of meaningful context to guide or bias perception.

A class of models that we term *modular interactive models* resolves this dilemma by including both modular and interactive components. The first stage of word processing is truly autonomous, taking information only from the stimulus (not from the context, unless perhaps by priming from lexical associates). In the particular model we propose, instead of emitting a single best candidate, the first stage emits or tags a set of candidates weighted according to the stimulus evidence for them. At the next stage, sentence context interacts with these weights to produce a single best candidate, which is the word consciously perceived. Models of this type include Norris's checking model (1986); other similar models have been proposed by Becker (1985; see also Paap, McDonald, Schvaneveldt, & Noel, 1987, and Paap, Newsome, McDonald, & Schvaneveldt, 1982);[1] Simpson, Peterson, Casteel, and Burgess (1989); Forster (1989); Rueckl and Oden (1986); Kintsch (1988); Marslen-Wilson (1987); and Altmann and Steedman (1988), among others.

Nonword Conversion

To study context effects in reading in the present experiments, we make use of a phenomenon we term the *nonword conversion effect* (Potter & Noel, 1987). Nonword conversion is the mistaken perception of a nonword as a word that it looks like. This effect has often been reported anecdotally (e.g., in proofreading) but has only occasionally been studied experimentally (e.g., Ehrlich & Rayner, 1981; Forster, 1974, 1989). As we show in Experiment 1, conversions of this kind are difficult to resist with rapid serial visual presentation (RSVP) of nonwords mixed with words, suggesting that the misreading happens at an early and automatic stage in processing. We then investigate whether and in what way this early perceptual stage is influenced by sentence and single-word context (Experiments 2–5).

The key theoretical question is what happens in the first 100 ms or 200 ms after a word (or nonword) appears. Thus it is important to limit processing time in some way. In the present studies, we use RSVP to constrain the time available for processing by embedding the critical stimulus in a sequence of other words—a list or a sentence—that also has to be processed. The rate used is 10 words/s (100 ms/word). No immediate response is made to the critical item, which is embedded in the ongoing sentence or list. Instead, the sequence is recalled immediately afterward, and the measure is the accuracy and pattern of errors in report of the critical item.

In RSVP, each word appears successively at the same place on the computer screen, so that each word masks the previous one and the reader has to register the word while it is in view. Studies have indicated that readers can understand and recall RSVP sentences presented as fast as 10 or 12 words/s (e.g., Potter, Kroll, Yachzel, Carpenter, & Sherman, 1986) but have difficulty recalling random lists as short as 4 or 5 words at these same rates (Potter, 1982). Thus, the reader evidently processes the sentence as it is read, rather than simply remembering the individual words and reconstructing the sentence afterward (for further evidence of on-line processing in RSVP, see Potter, 1984). In this respect, RSVP reading is like normal reading or listening.

To preview the present set of studies: In Experiment 1 we establish some characteristics of the nonword conversion effect in a neutral list context. In Experiment 2 neutral and biased sentences are presented with nonwords that look like two critical words (e.g., *dack*, *deck*, *duck*) as a first test between modular and interactive models. Experiment 3 asks

[1] Becker's verification model proposes a specific second-stage check that is different from the one proposed here in several respects, the most important being that it is prevented by backward masking within about 250 ms and thus would not operate at all in RSVP.

whether word priming in short lists can bias the perception of words and nonwords, as predicted by the lexical-priming modular model, and Experiment 4 asks whether there is bias from the overall meaning of a sentence, apart from lexical priming. Finally, Experiment 5 investigates a question that we argue is central to distinguishing between interactive and modular interactive models: Does selective information that arrives only after the critical word or nonword exert a significant biasing effect?

Experiment 1

The propensity to see or hear a nonword as a word has been noted in a number of previous studies, many of them concerned with auditory stimuli. Warren and his colleagues (e.g., Warren & Warren, 1970) found that subjects will restore a noise-replaced phoneme in a word without being aware that it was missing (the phoneme restoration effect; see also Samuel, 1981). Looking at isolated words with an ambiguous phoneme, Ganong (1980), Connine and Clifton (1987), and Elman and McClelland (1988) each found evidence for a perceptual bias toward words rather than nonwords (see also Connine, 1987, and Zwitserlood, 1989; for conflicting evidence, see McQueen, 1991). Using visual stimuli, Massaro (1979) found evidence for bias toward words in the perception of an ambiguous letter in a letter string. In all these experiments, the critical phoneme or letter was missing or distorted in some manner.

In the present experiments, the nonwords as well as the words were composed of unambiguous letters. In Experiment 1 subjects viewed and immediately recalled lists of two, four, or six items (always a mixture of words and nonwords) that were presented for 100 ms/word. Subjects were told that the lists would include some nonwords or "misspelled words," and they were encouraged to report exactly what they saw.

Method

Subjects. The subjects were 12 Massachusetts Institute of Technology student volunteers who were paid for their participation. All were native English speakers.

Materials and design. The materials consisted of 144 nouns of four, five, or six letters in length and 144 matched nonwords created by changing one vowel of each of the nouns to produce an orthographically regular pseudoword. At each word length, half of the words were high frequency and half were low frequency. The high-frequency words were between 33 and 100 per million in word frequency; the low-frequency, between 3 and 5 per million (Kucera & Francis, 1967). The 24 words in each of the six letter length by frequency groups were divided randomly into six lists, two each of 2, 4, and 6 words, with the constraint that adjacent words never shared more than one letter in the same letter position. A random half of the words on each list were changed to their matched nonword to produce one version of the experimental materials with 72 nonwords and 72 words. In a second version, the complementary words became nonwords. An example is shown in Table 1.

Apparatus. The experiment was run on a Terak microcomputer that had a refresh rate of 60 cycles/s.

Table 1
Sample Trial in Experiment 1

	Stimulus	
Duration (ms)	Version 1	Version 2
300	***	***
200	[blank]	[blank]
67	&&&&&&	&&&&&&
100	stule	style
100	motor	mitor
100	droam	dream
100	novel	nuvel
67	&&&&&&	&&&&&&

Note. Successive events are arrayed vertically. On the screen, the letters and symbols appeared in fixed locations, with the first letter of each word appearing in the position of the second ampersand, the second letter appearing in the position of the third ampersand, and so forth.

Procedure. The lists were presented using RSVP. Each trial was initiated when the subject pressed the spacebar. A row of asterisks appeared for 300 ms, a blank of 200 ms followed, and then the list was presented at 100 ms/item, preceded and followed by a 67-ms mask of six ampersands. Subjects recalled each list aloud immediately after it had been presented; if the experimenter had any doubt about the response, the subject was asked to spell the string. Subjects were told that the lists contained some nonwords that they should report verbatim; the proportion of nonwords (always .5) was not specified.

Scoring. The recall responses were matched to the stimulus items by the proportion of shared letters; 89% of the responses shared at least three of four, three of five, or four of six of the letters in target items of four, five, and six letters, respectively. Responses were classified as correct, as incorrect words (i.e., misreading a word as another word or converting a nonword to a word), as incorrect nonwords, or as omissions.

Results and Discussion

The main finding was that, although words were mostly reported correctly, nonwords were rarely reported correctly and were frequently reported as a similar-looking word (Table 2). Averaged over lists of different lengths, 57% of the stimulus words were recalled correctly and 10% were reported as being another similar-looking word. Nonwords were reported correctly only 10% of the time, which is not too surprising, given that they were unfamiliar strings. On 42% of the trials, nonwords were recalled as similar-looking words—the nonword conversion effect described earlier.

Table 2
Mean Percentage of Responses per Stimulus per List in Experiment 1: Mixed Lists of Words and Nonwords

	Response type		
Stimulus type	Correct	Incorrect word	Other[a]
Word	57	10	33
Nonword	10	42	48

Note. The list means were unweighted, so the different list lengths contributed equally to the per-item means shown.
[a] "Other" responses include omissions.

(Most of the nonwords were near orthographic neighbors not only of the word from which they had been generated, but also of one or more other words. Seventeen percent of the responses were conversions to the word of origin; the remaining 25% were conversions to some other word.) The reported words typically involved only a one-letter change from the nonword (a substitution, addition, or deletion of a letter). Of the remaining errors, most were omissions: 30% of the words and 40% of the nonwords were omitted.

Figure 1 shows a breakdown of the results by length of list. Keep in mind that because half of the items on a given list were words and half were nonwords, there was just one word and one nonword on the two-item lists, two of each on the four-item lists, and three of each on the six-item lists. Focusing on the two-item lists, note that although report of the one word was quite accurate (82% correct), the nonword was reported correctly on only 21% of the trials and was converted to a word on 56% of the trials. This high proportion of conversions even when only two items had to be remembered suggests that nonword conversion is not just a reconstructive memory effect. If the conversion from a perceived nonword to a word happened between initial (correct) perception and report, conversions should be reduced or eliminated when only two items have to be remembered. Instead, the proportion of conversions was higher for short lists than for longer ones. On the longer lists, a decreasing proportion of both words and nonwords were reported, consistent with the very limited memory span for unrelated words on lists presented at this rate (Potter, 1982, 1984).

Analyses of variance (ANOVAs) were carried out on the proportion (per item, per list) of correct responses and the proportion of intruded words, separately for word stimuli and nonwords. As Figure 1 shows, accuracy was higher the shorter the list: for words, $F(2, 22) = 91.19$, $p < .001$, $MS_e = 0.738$, and for nonwords, $F(2, 22) = 8.35$, $p < .01$, $MS_e = 1.425$. Nonword conversions to a word were proportionally higher on shorter lists, $F(2, 22) = 25.99$, $p < .001$, $MS_e = 0.897$. No other main effects were significant. It may be worth noting that word frequency of the stimulus word or the word of origin of the nonword had no significant effect on accuracy or on nonword conversions: For words, 58% of the words on high-frequency lists and 55% on low-frequency lists were reported correctly, averaging across list length.

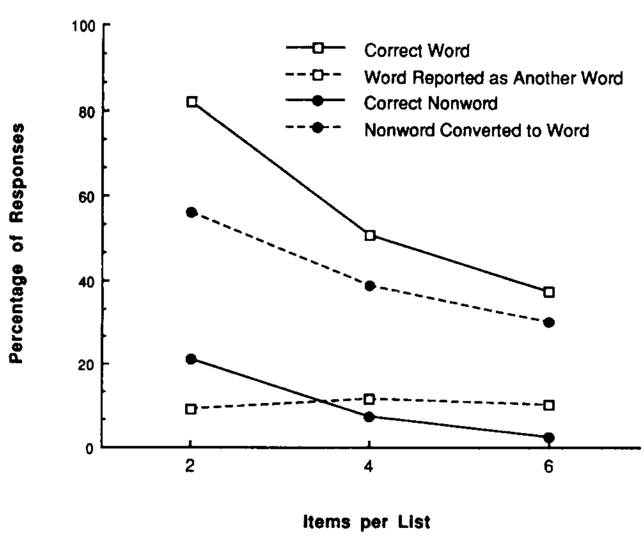

Figure 1. Percentage of responses as a function of list length for words and nonwords in Experiment 1.

Other nonword experiments. Three follow-up experiments in which lists of words and nonwords were presented are described briefly. In the first, which was an exact replication of Experiment 1 but with items presented for 150 ms instead of 100 ms, the question was whether nonword conversions would disappear at a duration at which word perception is highly accurate. Correct recall of both words and nonwords increased substantially (74% and 38% correct, respectively), and report of words as other words dropped to 5%. Nonetheless, nonword conversions were still substantial: 26% of the nonwords were converted to words. Thus, at a rate compatible with highly accurate word perception, the bias to see nonwords as words remained evident.

In a second follow-up experiment, the question was whether subjects would be able to avoid nonword conversions if they were informed about the actual percentage of nonwords (50%, in Experiment 1).[2] The same materials and rate (100 ms/item) were used as in Experiment 1, although there was a different microcomputer (an IBM XT; see Experiment 3). One group of 8 subjects was told that "there will be about 50% nonwords overall," and a second group of 8 subjects received the standard "there will be some nonwords" instructions. Although the first group reported a larger percentage of nonwords accurately than the second group (23% vs. 13%), both groups made a substantial number of conversions of nonwords to words (26% for the first group and 33% for the second). Words were reported equally accurately by both groups: 60% and 62%, respectively. Even though the first group was told that there would be 50% nonwords overall, 45% of their responses were words (correct or not) and only 19% were nonwords (correct or not), combining responses to both word and nonword stimuli. Thus, even when subjects are explicitly instructed about the proportion of nonwords, there remains a strong bias to convert nonwords to words. This result suggests that the bias occurs in a stage of perception not subject to conscious control.

In the third follow-up experiment, the question was whether nonword conversion is confined to letter changes involving vowels, which may be difficult to discriminate and are usually internal to the word. A new set of words was used, presented in lists of four items at 100 ms/item. The changed letter that created a nonword was equally often a vowel or a consonant, chosen randomly from all letter positions. Nonword-to-word conversions occurred for these stimuli also; the only distinctive finding was that conversions were unlikely to involve a change in the initial letter of the nonword stimulus. Similarly, Ehrlich and

[2] We thank Virginia Valian for suggesting this experiment.

Rayner (1981) found that in normal reading, misspellings were easier to detect when the initial letter of the word was changed.

Implications of the nonword conversion effect. Under the present conditions, conversion of a nonword to a word seems to happen automatically and rapidly, without time for reflection or conscious problem solving. Subjects were told that they would be seeing some nonwords and were instructed to report what they saw. Thus it is reasonable to assume that the converted word issued from the word processor rather than from a later problem-solving or strategic stage of processing.

The conversion effect (together with other evidence for word superiority) suggests that the word processor is designed to put out a single, best word candidate selected from the viewer's lexicon. A letter-level description of the stimulus reaches awareness later, if at all.[3] At 100 ms/item, the word candidate that emerges is usually the right one in the case of words, and a plausible but false word in the case of nonwords that are close to words. At slower rates, such as 150 ms/item, the output from the letter level permits correct report of many of the nonwords, but there is still a substantial percentage of cases in which a converted word "wins." At still slower reading rates, such as those associated with proofreading, the percentage of nonword conversions is still not negligible, judging from common experience (cf. Ehrlich & Rayner, 1981). Thus, processes resulting in nonword conversions are not restricted to RSVP. The experiments that follow study the effects of sentence and single-word contexts on nonword conversion and on word perception.

Experiment 2

Nonword conversion represents a bias to see letter strings as similar-looking words. The results of Experiment 1 and its follow-up experiments indicate that this bias occurs early in processing, so that it offers a good test case in which to evaluate the three classes of models we have listed. These models differ in their predictions about the effect of sentence context on early stages of word perception. The strong modular model predicts that nonword conversion will be independent of the preceding sentence context, whereas the interactive model and the modular interactive model both predict that context will have a biasing effect.

The main question addressed in Experiment 2 is whether nonword conversion is influenced by sentence context. A second question is whether, if there is bias, it is greater for nonwords than for words. Both interactive models predict such an effect, because the stimulus input to each item in the lexicon is weighted by the degree of evidence for it, and on the average the weights will be lower given nonword stimuli than given word stimuli. Modular models (apart from the modular interactive model) do not predict a difference in bias between converted nonwords and veridically perceived words, because both issue from the word-perception module without distinction: No differential weight is attached to indicate that the stimulus evidence for a converted nonword is any weaker than that for a veridically perceived word. To attach such a weight to the output would be to give up one of the central tenets of modularity: that the module makes its decisions autonomously and simply passes on the result.

The critical stimuli were triples consisting of two nouns such as *deck* and *duck* and a pronounceable nonword *dack* that were identical except for one vowel. The three critical stimuli were presented in neutral or biased sentences; an example is shown in Table 3. Note that, in the case of words, the bias was against the critical stimulus: Thus, our measure of bias for both words and nonword conversions was the *reduction* in reports of the critical item (the stimulus word or the nonword conversions to that word), compared with corresponding reports in the neutral context.

In an earlier experiment addressed to a similar theoretical question, Rueckl and Oden (1986) studied the influence of sentence context on the perception of a written word made ambiguous between two words (e.g., *bears–beans*) by altering a single letter. The letter was changed to a form intermediate between two letters (e.g., between *r* and *n*; cf. Massaro, 1979). The authors concluded that letter features and semantic context both contributed to word perception in a weighted (i.e., interactive) fashion, which they took to be support for a modular interactive model. Two differences between Rueckl and Oden's method and that of the present study are that, in the former study, there was no control over the time spent viewing the critical stimulus and sentence context, and no veridical response was possible when the critical word included a distorted letter. In the present study, RSVP was used to control viewing time, and a veridical response to the nonword was both possible and encouraged.

Method

Subjects. There were 32 subjects from the same pool used in Experiment 1, but none had participated in that experiment or the follow-up experiments. All were native English speakers. One additional subject was replaced because he exceeded the error criterion (more than 30% errors in recall of nontarget words).

Materials and design. Table 3 shows an example of the materials used in Experiment 2. Sixty-four pairs of four- or five-letter nouns were selected that were identical except for one vowel and that were similar in frequency, for example, *deck* and *duck*. A nonword was created by replacing the critical vowel with a third vowel: in this example, *dack*. Three sentences were written for each set of two words and a nonword: One sentence provided context that was compatible with one word, one with the other word, and the third was neutral between the two words but possible for each. The neutral sentences were much less constrained than the biased sentences, but even the biased sentences did not uniquely predict the critical word. However, the alternative word was a very poor fit to the biased sentence. More examples of the materials are given in Appendix A; the complete materials are available from Mary C. Potter.

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[3] Because nonwords or letter strings are sometimes reported as such, there is clearly some output from the letter level to a later stage of awareness. That output appears to be slower and less accurate than the output from the word level; thus a stimulus that is a word is more likely to be reported correctly than is a stimulus consisting of a nonword letter string in relatively brief displays.

Table 3
Example of a Word–Sentence Set for the Critical Words duck *and* deck *and Nonword* dack *in Experiment 2*

Sentence bias	Sentence and critical stimuli
duck	1. The child fed the *deck/dack* at the pond.
deck	2. The sailor washed the *duck/dack* of that vessel.
Neutral	3. The visitors noticed the *deck/duck/dack* by the house.

Each subject saw just one of the sentences in each of the 64 sets. Across versions of the experiment, each of the words appeared once with the biased-against sentence and once with the neutral sentence; the nonwords appeared with the two biased sentences in a set, and for balance each nonword appeared twice (across versions) with the neutral sentence. Thus, there were eight sentence–word/nonword combinations that were counterbalanced across subjects and materials, making eight versions of the experiment.

All-word filler sentences that were not anomalous constituted one third (32) of the trials. There were also 10 practice sentences with different materials that represented each of the types of sentences and words or nonwords in the experiment.

Measurement of bias. The neutral sentences were used as a baseline against which responses in the biased sentences were measured. When the critical stimulus was Word A (e.g., *deck* in Table 3, Sentence 1, or *duck* in Sentence 2), the biased sentence was always biased toward the other word, B. (The word actually presented, and biased against, is defined as A, and the other critical word is B.) Thus, for word stimuli, bias was measured as a reduction in veridical perception of A, compared with the neutral sentence.[4] The biasing effect was represented as the ratio of correct reports of Word A in the biased-against condition to the total correct reports of A in the biased-against plus the neutral conditions (note that there were an equal number of trials in each condition):

$$\text{Bias ratio} = \frac{\text{Word A reports given sentence bias toward B}}{\text{Word A reports given sentence bias toward B} + \text{Word A reports when A was presented in the neutral sentence.}} \quad (1)$$

This ratio can range from 0.0 to 1.0; a ratio of .5 means that there is no bias effect: The subject is as likely to report Word A correctly in the biased-against as in the neutral sentence. Ratios below .5 indicate bias toward the context.[5]

For nonword conversions, the corresponding measure of bias is the percentage reduction in the baseline (neutral) number of conversions to Word A, the word that was biased against in the biased sentences:

$$\text{Bias ratio} = \frac{\text{Word A conversions given sentence bias toward B}}{\text{Word A conversions given sentence bias toward B} + \text{Word A conversions in the neutral sentence.}} \quad (2)$$

Thus, for both word and nonword stimuli, the measure of the bias effect uses the neutral trials as the baseline estimate of the probability of a given output from the word processor, when the sentence context is minimally constraining with respect to the two critical candidates. Against this baseline, one measures the change (reduction) in reports of a given word, A, when the sentence is biased toward the other critical word, B.[6] These two ratios, one for word and the other for nonword trials, were calculated for each subject and, across subjects, for each item.

Apparatus. The experiment was run on the same Terak microcomputer used in Experiment 1.

Procedure. Each trial, which was initiated when the subject pressed the spacebar, began with three asterisks presented for 300 ms, followed by a 200-ms blank and the words of the sentence presented serially at the same location as the asterisks, for 100 ms a word. After the last word, a row of 10 percentage signs was presented for 67 ms. The task of the subject was to recall each sentence aloud immediately after it had been presented. Subjects were told, "There will occasionally be a highly improbable sentence, or a sentence that has a nonsense word or a misspelled word. Just say the sentence exactly as you saw it, and be sure to mention if there was a misspelled word." The experimenter recorded the response, asking the subject to spell the critical word if in doubt.

Results and Discussion

Marked bias effects were observed, and they were significantly larger for nonwords than for words. Both of these results accord with predictions of the two interactive models, whereas they contradict predictions of the strong modular model. According to that model, bias enters, if at all, only at a late, problem-solving stage. In the present experiment, the subject was warned to expect some misspelled words and some sentences that would not make much sense: Hence there was no incentive to engage the general problem solver to resolve anomalies. Subjects did pay attention to the instructions, because all of them correctly reported some anomalous words and some nonwords.

Percentage of responses. The percentage of responses of each kind, in each of the four stimulus conditions, is

[4] Scoring the *increase* in responses of the biased-toward Word B would be inappropriate for two reasons. First, for words, the biased-toward response is always an error and thus does not fulfill the condition that it be better supported by the stimulus input than the corresponding nonword conversion. Second, for nonwords, such an increase represents not only a switch away from the other critical word, but also a switch from omissions, from veridical reports of the nonword, and from other word conversions. Scoring the proportional *decrease* in reports in the biased compared with the neutral condition avoids these problems.

[5] The denominator in the ratio could have been simply the reports of Word A in the neutral condition, but then the ratio could have ranged from 0 to infinity. Using the sum of all Word A reports as the denominator uses a common method for restricting the range of the ratio without distorting it.

[6] Ratios are appropriately used when the theoretical question involves a predicted shift in frequency of a given response from one condition (neutral) to another (biased), and some other variable of interest (word vs. nonword stimulus) produces very different levels of performance in the baseline (neutral) condition. Changing the stimulus duration or some other stimulus variable to equate baseline performance on words and nonwords (as one reviewer suggested) would be inappropriate. The central issue is whether, when words and similar-looking nonwords are presented under the same viewing conditions, nonwords exhibit a larger bias effect, as is predicted if weaker stimulus evidence for a given response leads to a stronger top-down role of context.

Table 4
Percentage of Responses in Experiment 2: Biased and Neutral Sentences

	Word A stimulus		Nonword stimulus	
Response	Context neutral	Biased toward Word B	Context neutral	Biased toward Word B
Word A	68[a]	46[a]	12[b]	3
Word B	3	26	12[b]	40
Correct nonword	—	—	23	18
Other[c]	29	28	53[d]	39

Note. Each column is based on 512 trials. Word A is defined as the word presented and/or biased against, and Word B is defined as the word biased toward, on biased trials.
[a] Correct word. [b] Conversions to Words A and B were averaged, because there was no principled difference between them in the neutral, nonword condition. [c] The "other" responses included omissions and conversions to a word other than A or B. [d] The "other" responses included 12% conversions to a word other than A or B.

shown in Table 4. The effect of sentence bias on both words and nonwords is evident. For words, veridical responses to Word A (the presented word) were lower when there was bias toward B (46%) than when the context was neutral between A and B (68%): by subjects, $t(31) = 6.00$, $p < .001$, $SD = 0.20$; by items, $t(63) = 5.35$, $p < .001$, $SD = 0.32$. Similarly, for nonwords, when the sentence was biased toward B, there were fewer conversions to Word A (3%) than in the neutral condition (12%): by subjects, $t(31) = 6.39$, $p < .001$, $SD = 0.06$; by items, $t(63) = 6.08$, $p < .001$, $SD = 0.12$.[7] For words, mistaken reports of Word B in the biased condition increased from 3% in the neutral condition to 26%. For nonwords, the corresponding increase in conversions to Word B was from 12% to 40%.

For nonwords in the neutral condition, 24% of the responses were conversions to one of the two critical words, A or B, and another 12% were conversions to some other word. In addition to Words A and B, nonwords usually had several other one-letter-different orthographic neighbors into which they sometimes converted: for example, *dack* is a neighbor of *dank*, *dark*, *back*, and *dock*. Only the responses that were one of the two critical words in the design were included in the main analyses in the present experiments.

Bias ratios. To compare the size of the biasing effect on words versus nonwords, we considered only the Word A reports (row 1 in Table 4). It is Word A reports that potentially distinguish between modular and interactive models. Whereas strong modular models assume that a word that emerges from the word-perception module is unweighted and therefore equivalent whether it was generated veridically by a stimulus word or by mistaken perception of a nonword, interactive models assume that the weight of the perceptual evidence interacts with contextual information. For this reason, the biasing effect of context against conversion of a nonword to a given word (for which there is relatively weak perceptual evidence) should be greater than the biasing effect against veridical perception of a word (for which there is relatively strong perceptual evidence). Ratios were calculated using the formulas described in the *Method* section: reports of Word A in the biased-toward-B condition, divided by the sum of reports of A in both the biased and the neutral conditions. Recall that a ratio of .5 means there is no bias, and the smaller the ratio, the greater the bias. The means of subjects' ratios were .39 for words and .19 for nonwords. The bias effect was greater for nonwords than words: by subjects, $t(31) = 4.38$, $p < .001$, $SD = 0.25$; by items,[8] $t(53) = 6.43$, $p < .001$, $SD = 0.29$.

Inspection of the other results shown in Table 4 offers further qualitative support for the effectiveness of sentence bias. Misreadings of the critical word or nonword as the biased-toward word (shown in row 2) increased markedly in the biased condition, compared with the same misreading in the neutral condition.

Both interactive processing models predict not only that there will be a biasing effect of sentence context on word and nonword perception, but also that the effect will be greater for nonwords than for words. Again, that is because none of the word candidates activated by a nonword has as much perceptual evidence for it as does the correct candidate activated by a word. When perceptual evidence is weaker, sentence context effects should be stronger: just the result obtained in Experiment 2.

Recall, however, the modified modular model in which semantic priming from prior lexical items may occur within the lexical module. Would this modular model be able to account for the results of Experiment 2? Experiments 3 and 4 are addressed to this question.

Experiment 3

As noted earlier, the substantial evidence for semantic priming and other context effects prompted some modular theorists to propose that lexical associations are represented in the lexical module. The presentation of any word will activate not only it, but also its associates, for a short period of time. Thus, a sentence that includes the word *sailor* has some probability of activating the word *deck*, increasing the likelihood that "deck" will be reported when *duck* or *dack* is presented. The strongest evidence for such lexical priming

[7] All levels of significance reported in this article are two-tailed.
[8] Ten items with no conversions to the critical words in either context condition were omitted from this analysis.

has been found with two-word sequences in which the priming word immediately precedes (or appears simultaneously with) the target word (e.g., Meyer & Schvaneveldt, 1971).

The first step in assessing the role of lexical associations in the present materials is to determine whether potentially related words in the sentences (such as *sailor*) do prime the critical words and nonwords under optimal conditions for priming (Experiment 3). The second step is to dissociate lexical associations from sentence meaning, to evaluate the separate contributions of lexical priming and sentence-level meaning (Experiment 4). If lexical associations are the sole source of word-perception bias in sentences, then sentence-level meaning should have no independent effect.

In Experiment 3 we used the same design as that of Experiment 2, except that lists of three words (or two words and a nonword) were presented instead of sentences. The critical nonword or word was presented in sequence between two words taken from the sentences used in Experiment 2, using as the context words the two (one preceding the critical stimulus in the original sentence and one following it) that we judged most likely to be associated with the expected (biased-toward) word in the biased sentences and most related to either word in the neutral sentences. An example of the materials is given in Table 5.

Method

Subjects. There were 16 subjects from the same pool used in the earlier experiments, but none had participated in those experiments. An additional 2 subjects were replaced because they exceeded the error criterion (more than 30% errors in report of the two context words).

Materials and design. The materials were adapted from the 64 experimental sets of Experiment 2, but there were no fillers. Each trial consisted of three items: a context word, the target item (Word A, Word B, or the nonword), and a second context word. The context words were those judged by the experimenters to be most relevant to the meaning of the biased-toward word, in the corresponding sentences in Experiment 2; for the neutral sentences, the selected words were those that were judged most relevant to the two critical words. The first context word had appeared in the part of the sentence that preceded the target word, the second in the following part of the sentence. The context words are shown in italics in the sentences of Appendix A.

The general design was exactly similar to that of the experimental trials of Experiment 2. For each set of words, there were eight types of trials: four with word targets and four with nonword targets. Each of the two words was shown in the biased-against condition for that word and in the neutral condition. Each nonword appeared once in each of the two biased conditions and twice in the neutral condition, counterbalanced across versions.

Apparatus. The experiment was presented on an IBM XT with a fast-fade screen and a refresh rate of 60 Hz.

Table 5
Lexical Priming in Lists in Experiment 3

List bias	List		
duck	1. child	*deck/dack*	pond
deck	2. sailor	*duck/dack*	vessel
Neutral	3. visitors	*deck/duck/dack*	house

Procedure. Each trial started with a fixation array of five asterisks for 400 ms, followed by a blank for 200 ms, and then the three critical items for 100 ms each, ending with a mask consisting of a row of 12 dollar signs, for 100 ms. The subject reported the three items aloud. The subjects were instructed that there would be some nonsense or misspelled words and that they should report exactly what they saw (spelling if necessary).

Scoring and analysis. The bias ratio used in Experiment 2 was again calculated, based on the reports of the biased-against word divided by the total reports of that word in the biased-against plus neutral conditions. This ratio was calculated separately for word and nonword trials for each subject and each item.

Results and Discussion

The before-and-after prime pair produced very strong priming, both for nonwords and for words, indicating that lexical priming could in principle be a factor in the bias effect observed in Experiment 2. Subjects reported 87% of the context words (before and after the critical stimulus) correctly. The main results for the critical words and nonwords are shown in Table 6; a comparison with Table 4 shows that the pattern of results was very similar in the two experiments. The difference between the biased and neutral lists in the proportion of reports of the lexically biased-against word (row 1) was significant both for words and nonwords: for words, in the subject analysis, $t(15) = 3.44$, $p < .01$, $SD = 0.20$, and in the item analysis, $t(63) = 3.26$, $p < .01$, $SD = 0.42$; for nonwords, in the subject analysis, $t(15) = 4.73$, $p < .001$, $SD = 0.05$, and in the item analysis, $t(63) = 3.25$, $p < .01$, $SD = 0.14$.

Bias ratios were calculated for each subject and item, as previously described. The means of the subject ratios were .40 for words and .20 for nonwords, very close to the mean ratios of .39 and .19 in Experiment 2. Again, a comparison of the ratios for words and nonwords showed that the context effect was greater for nonwords than for words: by subjects, $t(14) = 3.02$, $p < .01$, $SD = 0.27$, and by items,[9] $t(33) = 2.73$, $p = .01$, $SD = 0.43$.

Inspection of the remaining results shown in Table 6 offers further evidence for the effectiveness of the lexical primes: misreadings of the critical word or nonword as the other, biased-toward word (row 2) increased substantially compared with the neutral condition, although not quite as much as in Experiment 2 with sentences.

Thus, the results of Experiment 3 are consistent with the hypothesis that the effect of context on word perception (and on nonword conversion) is mediated by lexical associations rather than by the meaning of the sentence. That is, we have shown that word associations have the potential to produce a biasing effect of the same magnitude as that observed in Experiment 2 with sentences. However, the conditions in Experiment 3 were chosen to be optimal for lexical priming: The associated words immediately preceded and followed the critical stimuli, whereas in the sen-

[9] Thirty items with no conversions to the critical words in either the neutral or biased-against conditions were omitted from this analysis.

Table 6
Percentage of Responses in Experiment 3: Lexical Priming

Response	Word A stimulus		Nonword stimulus	
	Context neutral	Biased toward Word B	Context neutral	Biased toward Word B
Word A	71[a]	54[a]	10[b]	4
Word B	4	18	10[b]	35
Correct nonword	—	—	18	14
Other[c]	25	28	62	47

Note. Each column is based on 256 trials. Word A is defined as the word presented and/or biased against, and Word B is defined as the word biased toward, on biased trials.
[a] Correct word. [b] Conversions to Words A and B were averaged, because there was no principled difference between them in the neutral, nonword condition. [c] The "other" responses included omissions and conversions to a word other than A or B.

tences of Experiment 2, there were almost always several words separating potential primes from the critical stimulus (see Appendix A, in which the priming words are italicized). Masson (1991) reviewed evidence indicating that priming by semantically related or associated words is largely eliminated when one or more unrelated words intervene between the prime and the target (but see Joordens & Besner, 1992, who found reduced but still significant priming with a single intervening word). Those results raise questions about whether purely lexical associations—as distinguished from a sentence-level representation of meaning—play a significant role in priming words in sentences (see also Carroll & Slowiaczek, 1986; Foss, 1982; Foss & Ross, 1983; Morris, Rayner, & Pollatsek, 1990; O'Seaghdha, 1989; Simpson et al., 1989; and Williams, 1988).

Experiment 4

Experiment 3 showed that lexical associates taken from the sentences of Experiment 2 were able to prime or bias perception of critical words and nonwords, as the lexical-priming version of the modular hypothesis predicts. In Experiment 4 we partially dissociate sentence-level meaning from lexical priming to pit the two possible sources of the sentence context effect against each other. Two versions of the context sentences were written. In the original ("old") version (the sentences used in Experiment 2, with minor changes), one of the two critical words was strongly biased toward, both by lexical items and by overall sentence meaning. That is, lexical associations and sentence-level bias were confounded, as in Experiment 2. In the new version of each sentence, the relevant lexical associates were maintained in the sentence, but minor changes were made so that the *other* target word was the one biased toward (at least weakly) by the meaning of the sentence as a whole. Table 7 shows one of the sentence sets.

According to the lexical-priming hypothesis, both versions of the sentence should produce a similar bias toward the original target; according to a sentence-level account of the original bias results, the bias should be reversed or at least reduced with the new version of the sentence.

Method

Subjects. There were 24 subjects from the same pool described previously. One additional subject was replaced because he exceeded the error criterion (more than 30% errors in recall of nontarget words).

Materials and design. Sets of four sentences were written for the word-word-nonword sets used in Experiments 2 and 3 (see Table 7). Two of the sentences were the biased sentences used in Experiment 2, sometimes modified in minor respects. The new sentences were written using all or almost all the words judged to have been associated with the target (e.g., detectives-trace-clue-mystery; political-leaders-truce-hostility-nations), and we at-

Table 7
Sentence-Level Bias Versus Lexical Priming in Experiment 4

Bias: Lexical	Bias: Sentence	Sentence and critical stimuli
		Old sentences
trace	*trace*	1. The two detectives found the *truce/troce* which was the clue to the mystery.
truce	*truce*	2. The political leaders made a *trace/troce* to overcome hostility between their nations.
		New sentence
trace	*truce*	1′. Only after the two detectives made a *truce/troce* were they able to uncover the clues to the mystery.
truce	*trace*	2′. The political leaders sensed a *trace/troce* of hostility between their nations.

tempted to avoid adding any new words strongly associated with the alternative meaning. Within those constraints, the sentence-level meaning was now more compatible with the other target word. However, it was often difficult to produce a strong reverse bias at the sentence level, given the presence of words representing concepts associated with the other target. No neutral sentences were used. More examples of the experimental sentences are shown in Appendix B; the complete materials are available from Mary C. Potter.

Between subjects, each of the four versions of a given sentence was presented with the nonword (here, *troce*) or the original biased-against word (e.g., detectives . . . *truce*), now biased toward at the sentence level in the new versions of the sentences. Altogether, there were 64 experimental trials and the 32 all-word, nonanomalous filler trials used in Experiment 2. There were 10 practice sentences with different materials that represented the types of sentences and words or nonwords in the experiment.

Procedure. The procedure was similar to that of Experiment 3, except that the words of the sentence were presented in place of the three words in Experiment 3. The trials began with a row of asterisks for 400 ms, followed by a blank for 100 ms and the words of the sentence for 100 ms each, ending with a mask of dollar signs for 100 ms. Subjects recalled the sentence aloud immediately after reading it. They were told that some of the sentences would not make sense and that words would sometimes be misspelled or nonsensical, but they should report exactly what they saw, spelling the nonword if necessary.

Results and Discussion

The overall sentence meaning had a major effect on both word and nonword perception, when pitted against the same strong lexical biases that had been so effective in list priming (Experiment 3). The results are shown in Table 8. The old sentences show the same pattern of results as the biased sentences in Experiment 2 (see Table 4).[10] However, the new sentences (which reversed the bias at the level of sentence meaning while retaining most of the original lexical bias) show a different pattern: They look much like the neutral sentences in Experiment 2. As the first row of Table 8 shows, correct reports of the stimulus word and conversions of the nonword to that word were both substantially greater when supported by sentence-level meaning. That is, the sentence-level bias had a major effect, when lexical bias was held approximately constant. This difference between the old and new sentences in the proportion of reports of the lexically biased-against word (row 1) was significant both for words and nonwords. For words, by subjects, $t(23) = 4.16, p < .001, SD = 0.20$; by items, $t(63) = 4.13, p < .001, SD = 0.32$. For nonwords, by subjects, $t(23) = 6.73, p < .001, SD = 0.066$; by items, $t(63) = 4.35, p < .001, SD = 0.17$.

To compare the relative size of the sentence-level bias effect for words and nonwords, we again used a ratio measure, based on individual subject and item data corresponding to row 1 of Table 8. The ratio consisted of reports of the lexically biased-against word in the old sentence (Word A) divided by the sum of reports of that word in the old sentence and the new sentence. The ratios were calculated separately for word and nonword stimuli, for each subject and item. A ratio of .5 would show that sentence-level meaning had no biasing effect (apart from lexical bias, which was held constant), whereas a ratio smaller than .5 would indicate that there was sentence-level bias in addition to lexical bias. For words, the mean of subject ratios was .42, and for nonwords, .19, $t(22) = 5.32, p < .001, SD = 0.21$, and in the item analysis, $t(33) = 3.36, p < .003, SD = 0.35$. Thus, although there was sentence-level bias for both words and nonwords, the proportional bias effect was significantly greater for nonwords than for words, as in the earlier experiments.

The increase in Word A responses with the new sentences was accompanied by a decrease in Word B responses, as row 2 of Table 8 shows. For nonwords, combined lexical and sentence-level bias—the old sentences—produced 38% reports of the biased-toward word, Word B. When the sentence-level bias was reversed—the new sentences—reports of Word B dropped to 20% but remained higher than the 13% reports of Word A, $t(23) = 2.66, p < .02, SD = 0.12$, showing that lexical bias was still somewhat stronger than sentence-level bias in the new sentences, at least for nonwords.

In conclusion, although Experiment 3 showed that a lexically related word was sufficient to produce very substantial biasing of both nonwords and words in short lists, Experiment 4 shows that sentence context effects of the kind observed in Experiment 2 are not due solely to lexical priming, but are also determined by sentence meaning. Therefore, even though lexical associations may contribute to sentence context effects in the manner suggested by the modified modular model, lexical priming cannot wholly account for interactive effects of sentence context on word and nonword perception. Sentence-level meaning matters also, as the interactive models claim.

Experiment 5

Experiments 2–4 indicate that sentence context interacts with word perception. Two interactive models of word processing were considered in the introduction. In a simple interactive model, stimulus information and contextual information are combined in a single step. This step may have internal structure, such as the feature, letter, word, syntactic, and semantic levels in McClelland's 1987 model, but because there is two-way activation between each successive level the whole system is directly or indirectly interconnected, with later levels influencing earlier levels and vice versa. We can idealize this mutual influence on word perception as a single step. In a modular interactive model there are two steps. First, a modular word processor uses only bottom-up, stimulus information to select a set of word candidates, weighting them according to the strength of the stimulus evidence. In the second step, these weighted lexical candidates are matched interactively with contextual infor-

[10] The reader may notice that three of the four numbers in the first row of Table 8 are identical to those in Table 6: This is a coincidence, not an error.

Table 8
Percentage of Responses in Experiment 4: Sentence-Level Versus Lexical Bias, With Lexical Bias Always Toward Word B

	Word A stimulus		Nonword stimulus	
Response	New sentence biased → A	Old sentence biased → B	New sentence biased → A	Old sentence biased → B
Word A	71[a]	54[a]	13	4
Word B	6	23	20	38
Correct nonword	—	—	17	22
Other[b]	23	23	50	36

Note. Each column is based on 384 trials. Word A is defined as the word presented and/or biased against lexically; Word B is defined as the word biased toward lexically.
[a] Correct word. [b] The "other" responses included omissions and conversions to a word other than A or B.

mation to come up with a single best candidate. Only at that point does the reader become aware of the word.

The two models make many of the same predictions, as we have seen. Experiment 5 tests a prediction that distinguishes between them. In the modular interactive model, the first autonomous processor generates a set of candidates on the basis of the letter string. In principle, this set of candidates could remain activated after the stimulus has been replaced by the next word. This might permit contextual information that comes after the critical stimulus to influence the selective process. In the one-step interactive model, in contrast, interaction of stimulus and higher level information requires that all the relevant information be concurrently active, so that semantic context can in principle percolate down to the letter or feature level. Delaying the contextual information until after the next word begins to be processed would be expected to eliminate the biasing effect of the context, because now a new set of features and letters would be activated.

This argument assumes that the lower level stimulus information that is input to a one-step word processor will have less persistence and be more subject to interference from the next stimulus word than the word candidate or candidates that are output from a first-stage, modular word processor. In the interactive model, feature- or letter-level representations of a given stimulus would be masked by the subsequent stimulus word's features and letters, so it would be essential to settle on the best word candidate before the next stimulus begins to be processed. In contrast, the output of the first, autonomous stage of the modular interactive model is a set of word candidates in the lexicon that are abstracted from the visual features of the input and hence would be less subject to masking by the features and letters of the next stimulus. Activated lexical entries would only be likely to be interfered with by similar or identical word candidates elicited by subsequent words in the sentence, and similar words are unlikely to appear near each other in a sentence. (Note that when a later word is identical or in the same orthographic or phonological neighborhood, forward masking produces "repetition blindness," as shown by Bavelier & Potter, 1992; Kanwisher, 1987; and others.) Thus, the interactive model would offer little opportunity for effects from subsequent context, whereas the modular interactive model, with its multiple lexical candidates, could allow some influence from later context. We consider this difference between the models in greater detail in the General Discussion.

Temporally backward biasing effects on word perception have previously been reported for acoustic stimuli by Warren and Warren (1970), who described a study by Sherman in which sentence context following a noise-replaced phoneme in a word biased phoneme restoration (see also Pollack & Pickett, 1964). Similarly, Connine, Blasko, and Hall (1991) found that perception of spoken words made ambiguous by varying the voice onset time of a critical phoneme could be influenced by sentence context that followed the ambiguous word. For pairs of visual words, Kiger and Glass (1983) found that a semantic prime with an onset 50–65 ms after the target stimulus facilitated a lexical decision; they theorized that the two words were processed in parallel, with bidirectional priming (see also Briand, den Heyer, & Dannenbring, 1988; Jacobson & Rhinelander, 1978; Stone & Van Orden, 1989; and Whittlesea & Jacoby, 1990). However, in none of these studies with visual words has the effect of subsequent sentence context been examined. A single exception is in an unpublished experiment of Forster and Hall, cited by Forster (1974): They found that context following a pair of verbs in an RSVP sentence influenced which verb was reported, given that only one verb was syntactically and semantically acceptable.

In Experiment 5 we used biased sentence contexts like those in Experiment 2. For each word pair there were two basic sentences, one biased toward each word. Two versions of each basic sentence were written, one in which there was strongly biasing context before the critical word and a second version in which the context before the critical word was the same for both sentences: The sentences diverged only after the critical stimulus, to implicate one of the words and rule out the other. Table 9 shows one set of the materials. A disambiguating word appeared as the second or third word following the critical stimulus, although occasionally the word immediately following was also somewhat constraining. The biasing material was similar in the before and after versions of a given sentence. Note also that in the before condition, some of the relevant context appeared before the critical item, but some also appeared after it (as in the earlier experiments).

Table 9
Context Before and After the Critical Stimulus in Experiment 5

Sentence bias	Context	Sentence and critical stimuli
race	Before	1. She ran her best time yet in the *race/rice/roce* last week.
race	After	2. In the *race/rice/roce* she ran her best time yet last week.
rice	Before	3. For supper she cooked *race/rice/roce* with vegetables.
rice	After	4. In the *race/rice/roce* she cooked for supper there were vegetables.

The general design was similar to that of Experiment 4. Sentences were biased toward one or the other word, the biasing information came before or only after the critical stimulus, and the critical stimulus was the expected word, the unexpected word, or the nonword.

Method

Subjects. There were 32 subjects from the same pool described previously. Four additional subjects were discarded because they exceeded the error criterion (more than 30% errors in recall of nontarget words).

Materials and design. The same 64 word sets from the previous experiments were used in Experiment 5. As in Experiment 2, there were two basic sentences for each set, one biased toward each of the two words. Each of these sentences had two versions, one in which the relevant selective context came only after the critical word and the other in which some of the selective context came before the critical word. In the after-context versions, the initial part of the sentence was identical for the two basic sentences; selective context was introduced two or three words after the critical word. In the before version, some of the selective context was moved to the beginning of the sentence. To the extent possible, the same contextual information was used in the before and the after versions of a given sentence.

Thus, there were four sentences in each set, and each was shown with one of three critical items: the appropriate word, the inappropriate word, or the nonword (multiplied by 2, to balance the design). A given subject saw only one of these 16 versions of each of the 64 sets of materials, counterbalanced so that each subject had four trials in each of the 16 conditions. Collapsing over the two basic sentences in a given set (e.g., the *duck* sentence and the *deck* sentence), there were eight trials in each of 8 conditions: before–after context, word–nonword, and match–mismatch word. (The latter variable was a dummy variable in the case of nonwords.) There were no filler sentences. More examples of the materials are shown in Appendix C; the complete materials are available from Mary C. Potter.

Procedure. The procedure was similar to that of Experiment 4. Each trial began with a fixation point for 400 ms, followed by the words of the sentence for 100 ms each and a final mask of percentage signs for 100 ms. Subjects recalled the sentence aloud immediately after reading it. They were told that some of the sentences would not make sense and that words would sometimes be misspelled or nonsensical, but they should report exactly what they saw, spelling out if necessary. There were 14 practice trials.

Measurement of bias. As in the previous experiments, both the percentage of reports of each word in each condition and the ratio measures were used to assess context effects. For the ratios, the sum of reports of a word when the context was biased against that word were divided by reports of that word summed over both biased-against and biased-toward conditions. This ratio was calculated for each subject and item in each condition (word–nonword and before–after).

Results and Discussion

Substantial context effects were observed when the relevant context came after the critical stimulus as well as when the context came before, although the effects in the after condition were significantly smaller. The before–after difference in the biasing effect was equivalent for words and nonwords. The main results are shown in Table 10.

The condition most similar to those of Experiment 2 (biased) and Experiment 4 (biased, old sentences) was the before, biased-toward-B condition, and the results for words and for nonwords were very similar to the corresponding

Table 10
Percentage of Responses in Experiment 5: Sentence Bias Before or After the Critical Stimulus

	Word A stimulus				Nonword stimulus			
	Before		After		Before		After	
Response	Bias → A	Bias → B	Bias → A	Bias → B	Bias → A[a]	Bias → B	Bias → A[a]	Bias → B
Word A	85[b]	46[b]	94[b]	76[b]	34	3	24	6
Word B	1	26	1	15	3	34	6	24
Correct nonword	—	—	—	—	25	25	44	44
Other[c]	14	28	5	9	38	38	26	26

Note. For words, each column is based on 256 trials; for nonwords, 512 trials. For words, Word A is defined as the word presented on a given trial, and Word B is defined as the other word.
[a] For nonwords, there was no principled distinction between bias toward A and toward B: The same data are simply rearranged to facilitate comparison with the two bias conditions for words. [b] Correct word. [c] The "other" responses included omissions and conversions to a word other than A or B.

results in the earlier experiments (Tables 4 and 8). Thus, we successfully replicated the earlier results in this condition, in which sentence and lexical bias were pitted against the word stimulus and against nonword conversion to that word. Bias toward the stimulus word (Word A, in Table 10) and the corresponding nonword led to much more frequent reports of that word than when the bias was against it.

Now consider the after condition. Again, both for words and for nonwords, there is substantial evidence for bias, although not as much as when the differential context came before the critical word or nonword.

An ANOVA of correct reports of Word A (for word trials only) showed significant main effects of the direction of sentence bias, $F_{min}(1, 68) = 42.85$, $p < .001$, $MS_e = 2.418$, and of before versus after context, $F_{min}(1, 94) = 28.81$, $p < .001$, $MS_e = 0.948$. The interaction between sentence bias and before–after was also significant, $F_{min}(1, 87) = 9.61$, $p < .001$, $MS_e = 1.088$, with the biased-against before condition reducing the accuracy of report more (46%) than the after condition (76%), whereas with the biased-toward sentences the before condition actually had less of a positive effect (85%) than the after condition (94%). This last difference (significant by a Newman-Keuls test) was unexpected and is probably explained by the fact that when the relevant context came after the critical stimulus, the serial position of the stimulus was earlier, on the average, than when the relevant context preceded the critical stimulus. The probability of recalling a word in a sentence decreases somewhat, the later it appears in the sentence.

The bias ratios are shown in Table 11. As before, a ratio of .5 would mean that there was no biasing effect, and the smaller the ratio the larger the bias. The ratios in Experiment 5 were based on biased-against versus biased-toward conditions, not biased-against versus neutral conditions as in Experiments 2 and 3, nor biased-against old versus new sentences as in Experiment 4. Hence the absolute sizes of the ratios in this experiment cannot be directly compared with those in the earlier experiments. All four ratios were significantly below .5: for words, in the before condition, $t(31) = 6.71$, $SD = 0.143$; in the after condition, $t(31) = 4.92$, $SD = 0.071$; for nonwords, in the before condition, $t(31) = 19.69$, $SD = 0.119$; in the after condition, $t(31) = 3.74$, $SD = 0.307$ (for all *t*s, $p < .001$, two-tailed).

An ANOVA was carried out on the ratios, calculated both by subjects and by items. There was a significant difference between the sizes of the bias effect in the two context conditions: Prior context was more successful than subsequent context in biasing the interpretation, $F_{min}(1, 106) = 12.15$, $p < .001$, $MS_e = 0.036$. The bias effect was markedly stronger for nonwords than for words, as in the previous experiments, $F_{min}(1, 79) = 25.41$, $p < .001$, $MS_e = 0.025$; this difference did not interact with before–after context, $F_1(1, 31) = 3.09$, $p = .089$, $MS_e = 0.027$, and $F_2(1, 63) = 0.19$, $p > .30$, $MS_e = 0.050$, showing that both words and nonwords are subject to revision after presentation.

Table 11
Mean Subject Response Ratios in Experiment 5: (Biased-Against)/(Biased-Against + Biased-Toward) Responses

	Sentence bias	
Stimulus type	Before	After
Word	.33	.44
Nonword	.09	.30

Note. Ratios significantly below .5 indicate bias.

The striking finding in Experiment 5 was that biasing context coming 200–300 ms after the onset of the critical item could still have a major influence. For this to happen, the subject must have correctly recognized and interpreted the two or three following words while still maintaining a malleable representation of the critical item. This result is more consistent with the modular interactive model than with a one-step interactive model. The modular interactive model assumes that the output of the initial step in word processing is a set of candidates with weights attached that represent the degree of support for each candidate. At the next step, information provided by the sentence context interacts with these weights to select a single best candidate. If we make the further assumption that the initial slate of candidates remains available for a short period after the word or nonword has been viewed, then later evidence could determine what word (if any) is finally seen (see Kintsch, 1988, for a compatible approach).

How might a standard one-step interaction model explain these results? The relevant stimulus information from the critical word or nonword would need to persist while the next few words of the sentence were processed. It is doubtful that the persisting information could be in the form of a visual icon, because iconic memory would not survive pattern masking by the next words; similarly, more abstract visuospatial short-term memory is not thought to survive a shift in attention (Phillips, 1974), as would be required to process the following words. For the same reason, representations at the level of visual features or letters are not likely to be stable. Because the interaction model proposes that both stimulus-driven processing and context-driven processing activate lexical items, a more plausible suggestion is that all words activated by the critical stimulus remain activated for a time, allowing for the influence of contextual information that arrives later; however, that is simply an ad hoc version of the modular interactive model. Thus, the results of Experiment 5 support the modular interactive model over the one-step interactive model.

General Discussion

The present study used a new technique, nonword conversion, to answer a question about initial word perception in reading sentences: Is it interactive or autonomous? The results indicate that the evolving meaning of the sentence biases perception of successive words, supporting some form of interaction. In Experiment 1 we documented the conversion phenomenon, which is a strong and irresistible propensity to see nonwords as similar-looking words, when the rate of presentation is high but slow enough for generally veridical reports of words. That is, at rates that allow unbiased words to be reported with considerable accuracy (apart from memory limitations), nonwords are not likely to be reported accurately but are frequently converted to similarly spelled words. The phenomenon is consistent with such parallel interactive models of word perception as McClelland and Rumelhart's 1981 model and its more recent versions. What the RSVP technique appears to do is to halt the perceptual processing of each successive word at an early stage, a stage at which a word candidate (usually the right one) has become dominant but perception is not complete. At this early stage, a nonword may activate one or more orthographically similar word or words in the lexicon and be misperceived as a word.

The use of the nonword conversion methodology made it possible to examine the effects of context at the early stage of visual word recognition about which interactive and modular models disagree. Because the nonword in Experiments 2–5 was equidistant between two critical words, the context effect (if any) could be measured as a shift away from reports of one of the words when the context was biased toward the other word. The subjects were encouraged to report exactly what they saw (including misspelled or nonsensical words), and they did report many nonwords (and contextually anomalous words) correctly; thus, the nonword conversions and word errors that did occur are unlikely to have been strategic.

In Experiment 2 we tested whether sentence context interacts with visual information about a word at this early stage of processing. The biasing effect of context was already strongly in evidence, even when each word or nonword was seen for only 100 ms. The bias was relatively greater for nonwords than for words, indicating that there is an interaction between the extent of evidence for a word and the influence of context. (This interaction was observed in Experiments 3–5 also.) This result supports interactive processing models rather than the strong modular model.[11]

Lexical Priming in Sentences?

Experiments 3 and 4 addressed a modified version of the modular hypothesis, which claims that sentence context effects of the kind observed in Experiment 2 and in other studies are due to associations between words in the lexical module, independent of sentence-level meaning. Experiment 3 showed that a lexical triple, in which the first and last words are strongly associated with a given word, can bias the perception of a critical middle stimulus that looks like that word. The effect was similar in magnitude to the effect of the full sentence in which those context words had appeared (Experiment 2).

Although that result supported the lexical-association account of higher level context effects on word perception, the results of Experiment 4 (as well as other studies reviewed by Masson, 1991) suggest otherwise. In Experiment 4, reversing the sentence-level bias while retaining the critical lexical associates—that is, pitting sentence-level bias against lexical bias—markedly reduced lexical bias both in nonword conversions and in word perception. Thus, prestored word associations within the lexicon cannot by themselves explain all sentence-context effects.

Do the results of Experiments 3 and 4 nonetheless show that lexical associations play some role in word perception, both in lists and in sentences? The case is not proved: "Lexical" priming may be the result of conceptual associations outside of the lexicon. For example, Vanderwart (1984) has shown that pictures can prime target words just as well as their names can, even when the stimulus onset asynchrony is too brief for the subject to have named the picture prime: Thus, the priming effect results from conceptual rather than lexical links. Nor are priming effects confined to words that have appeared together in discourse and that might have become associated simply by contiguity.

Indeed, the strong priming effects observed in Experiment 3 are more likely to result from processing designed to recover propositions than from automatic, low-level lexical associations. As Experiment 5 shows, both preceding and following sentence context have an influence on word perception in the present paradigm. Hence, both of the context words in Experiment 3 are likely to have contributed to the bias effect. Inspection of the three-word (or nonword) sequences (see Appendix A) indicates that many of them suggest telegraphic messages with a phrasal or propositional character (e.g., *defendant-bench-trial/grape-bunch-breakfast; letter-stamp-corner/tree-stump-road;* and *sailor-deck-vessel/child-duck-pond*). Thus, in a manner similar to the effect of the whole sentence context in Experiment 2, the reduced propositions, arguments, or scenarios suggested by the two context words plus one of the word candidates activated by the critical stimulus may have been sufficient to produce the observed bias.

Interactive Models

We conclude from Experiments 2–4 that an interactive model is necessary to account for the whole set of results. We considered two interactive models: one in which the interactions take place in a single step and a second, the modular interactive model, in which multiple candidate words are activated bottom-up in a first stage, tagged with perceptual weights. At a second stage, contextual information is combined interactively with these weights to select a single best candidate: Ordinarily, it is only this candidate of which the reader is aware. One prediction of such a model is that the candidates activated autonomously in the first stage might remain available beyond the time at which the stimulus is perceptually present, opening the possibility that immediately following context might have an influence on selection.

[11] One may ask whether the present findings are likely to apply to normal reading. The case for the equivalence of RSVP reading and conventional reading has been made more fully elsewhere (e.g., Potter, 1984; Potter et al., 1986). Here, the rather high accuracy in perception of words that fit the context (including the context words themselves) supports the assumption that the reading conditions of the present experiments reflect many of the processes of normal reading, while reducing the opportunities for error checking that would normally be available.

Experiment 5 tested that prediction by comparing sentences in which discriminative context came before the critical stimulus versus only after it (but within 100–300 ms). What we found was that context coming only after the critical item affected both word and nonword perception significantly (even though not as much as relevant context before the critical item), thus showing that initial perception is subject to correction for at least the next 300 ms, under the conditions of the present experiments. (Of course, such "corrections" were in fact errors, in most of the conditions in the present experiments.)

This result is most compatible with the modular interactive model. Other recent results in our laboratory in which two candidate words are presented simultaneously and briefly at a given point in a sentence (Potter, 1990) offer further support for the modular interactive model's separation of a stimulus-driven stage (which produces a hierarchy of candidates) from the context-interactive stage that selects a final candidate. Biasing context that came as late as 1 s after the critical pair of stimuli was able to exert a marked influence on which word was chosen (and subjects were usually unable to remember the nonselected alternative afterward). For this to happen, the subject must have correctly recognized and interpreted up to about seven of the following words, while still maintaining some level of activation of both of the competing critical words until the final choice was made.

In the present experiments, it is unlikely that a representation of the visual or orthographic stimulus could still be available several hundred milliseconds after presentation, given the masking produced by RSVP; a more stable representation such as a lexical representation would be required. The modular interactive model is consistent with these conflicting requirements for malleability and stability, because it assumes that the output of the word processor is not necessarily a single word, but rather a set of weighted candidate words (the weights represent the degree of support for each candidate). If we make the further assumption that these word candidates, with some information about their meanings, remain available for a short period after the word or nonword has been viewed, then later evidence could determine in an interactive fashion which word (if any) is finally seen.

Notice the analogy of this process to that needed to disambiguate a homonym, when two or more lexical entries are activated and remain activated until there is enough information to make a choice between them (e.g., Swinney, 1979). The modular interactive model of word perception assumes that in the first stage several word candidates are proposed; the second stage, in which context interacts with the candidates, is in fact identical with that required for disambiguation of a homonym (Norris, 1986). Thus, whether the source of the multiple candidates is a single orthographic or phonological form with multiple meanings (lexical entries) or an incompletely perceived letter string that is orthographically similar to more than one word, the same second-stage process can determine the selection. That process can operate whether the relevant context precedes or only follows the homonym or the incompletely perceived word.

An important question that remains to be addressed is how the processor links together the set of candidates for a single word slot in such a way that they continue to compete for just that one slot even as the following word stimuli are generating their own sets of candidates. Even though the sentences were presented at the rate of 10 words a second in the present experiments, subjects rarely reported 2 words in response to a single stimulus, indicating that the word processor is strongly constrained to converge on a single word, at most, for each letter string. If the selection occurred immediately, word by word, such a constraint would be readily implemented. But Experiment 5 indicates that convergence on a given word may not occur until several further words have been processed, or if a decision was made initially, it remains open to change, and a perceptually similar candidate may be substituted later. In either case, some mechanism for linking the candidates to the proper slot would be necessary. One possibility is that there is some temporal window within which all newly activated candidates are bound; another possibility is that orthographic or phonological similarity forces activated words into competition (as suggested by repetition blindness for orthographically or phonologically similar words that are temporally separated; Bavelier & Potter, 1992; Kanwisher & Potter, 1990).

Role of Bias in Veridical Perception

Bias, which can in principle enter processing at any stage (e.g., Ratcliff, McKoon, & Verwoerd, 1989), plays two roles in the present work. First, we show that readers are involuntarily biased to see letter strings as words (cf. Estes & Brunn, 1987). Second, we argue that sentence context is used in early stages of word perception to select among candidates activated by the visual stimulus, introducing a perceptual bias toward one word rather than another. This second bias makes anomalous words more difficult to see accurately and interacts with the first bias to markedly affect the probability that a nonword will be converted to a given word. As signal detection theory (and Bayes's theorem) indicates, bias that is responsive to the probability structure of events enhances overall performance. The same principle underlies the constraints that make visual perception computationally possible (e.g., Marr, 1982). Thus, it is exactly the sensitivity of word perception to sentence meaning that makes reading and listening normally so accurate—at the minor cost of missing an improbable or misspelled word, particularly when it happens to look or sound like a more probable one.

Conclusion

The present experiments show that under conditions that provide minimal time for processing each word in a sentence, the meaning of the sentence interacts with perception of successive words. This interaction permits the correct perception of words consistent with the context while inducing context-appropriate errors in the perception of anomalous words and nonwords that are orthographic neighbors of an appropriate word. The finding that there is a significant effect of context that follows the critical stimulus suggests that a weighted set of candidate words is initially activated in a context-free manner; in a second stage, this set interacts with contextual information to converge on the single word that is consciously perceived.

References

Altmann, G., & Steedman, M. (1988). Interaction with context during human sentence processing. *Cognition, 30,* 191–238.

Balota, D. A. (1990). The role of meaning in word recognition. In D. A. Balota, G. B. Flores d'Arcais, & K. Rayner (Eds.), *Comprehension processes in reading* (pp. 9–32). Hillsdale, NJ: Erlbaum.

Bavelier, D., & Potter, M. C. (1992). Visual and phonological codes in repetition blindness. *Journal of Experimental Psychology: Human Perception and Performance, 18,* 134–147.

Becker, C. A. (1985). What do we really know about semantic context effects during reading? In D. Besner, T. G. Waller, & E. G. MacKinnon (Eds.), *Reading research,* (Vol 5, pp. 125–169). San Diego, CA: Academic Press.

Briand, K., den Heyer, K., & Dannenbring, G. L. (1988). Retroactive semantic priming in a lexical decision task. *Quarterly Journal of Experimental Psychology, 40A,* 341–359.

Carroll, P., & Slowiaczek, M. L. (1986). Constraints on semantic priming in reading: A fixation time analysis. *Memory & Cognition, 14,* 509–522.

Connine, C. M. (1987). Constraints on interactive processes in auditory word recognition: The role of sentence context. *Journal of Memory and Language, 26,* 527–538.

Connine, C. M., Blasko, D. G., & Hall, M. (1991). Effects of subsequent sentence context in auditory word recognition: Temporal and linguistic constraints. *Journal of Memory and Language, 30,* 234–250.

Connine, C. M., & Clifton, C., Jr. (1987). Interactive use of lexical information in speech perception. *Journal of Experimental Psychology: Human Perception and Performance, 13,* 291–299.

Ehrlich, S. F., & Rayner, K. (1981). Context effects on word perception and eye movements during reading. *Journal of Verbal Learning and Verbal Behavior, 20,* 641–655.

Elman, J. L., & McClelland, J. L. (1988). Cognitive penetration of the mechanisms of perception: Compensation for coarticulation of lexically restored phonemes. *Journal of Memory and Language, 27,* 143–165.

Estes, W. K., & Brunn, J. L. (1987). Discriminability and bias in the word-superiority effect. *Perception & Psychophysics, 42,* 411–422.

Fodor, J. A. (1983). *The modularity of mind.* Cambridge, MA: MIT Press.

Fodor, J. A. (1985). Precis of "The modularity of mind" and commentary and response. *Behavioral and Brain Sciences, 8,* 1–42.

Forster, K. I. (1974). The role of semantic hypotheses in sentence processing. In F. Bresson & J. Mehler (Eds.), *Current problems in psycholinguistics* (pp. 391–408). Paris: Editions du CRNS.

Forster, K. I. (1979). Levels of processing and the structure of the language processor. In W. Cooper & E. Walker (Eds.), *Sentence processing: Psycholinguistic studies presented to Merrill Garrett* (pp. 27-85). Hillsdale, NJ: Erlbaum.

Forster, K. I. (1989). Basic issues in lexical processing. In W. Marslen-Wilson (Ed.), *Lexical representation and process* (pp. 75–107). Cambridge, MA: MIT Press.

Foss, D. J. (1982). A discourse on semantic priming. *Cognitive Psychology, 14,* 590–607.

Foss, D. J., & Ross, J. R. (1983). Great expectations: Context effects during sentence processing. In G. B. Flores D'Arcais & R. J. Jarvella (Eds.), *The process of language understanding* (pp. 169–191). New York: Wiley.

Ganong, W. F. (1980). Phonetic categorization in auditory word perception. *Journal of Experimental Psychology: Human Perception and Performance, 6,* 110–125.

Jacobson, J. Z., & Rhinelander, G. (1978). Geometric and semantic similarity in visual masking. *Journal of Experimental Psychology: Human Perception and Performance, 4,* 224–231.

Joordens, S., & Besner, D. (1992). Priming effects that span an intervening unrelated word: Implications for models of memory representation and retrieval. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 18,* 483–491.

Kanwisher, N. G. (1987). Repetition blindness: Type recognition without token individuation. *Cognition, 27,* 117–143.

Kanwisher, N. G., & Potter, M. C. (1990). Repetition blindness: Levels of processing. *Journal of Experimental Psychology: Human Perception and Performance, 16,* 30–47.

Kiger, J. I., & Glass, A. L. (1983). The facilitation of lexical decisions by a prime occurring after the target. *Memory & Cognition, 11,* 356–365.

Kintsch, W. (1988). The role of knowledge in discourse comprehension: A construction-integration model. *Psychological Review, 95,* 163–183.

Kucera, H., & Francis, W. N. (1967). *A computational analysis of present-day American English.* Providence, RI: Brown University Press.

Marr, D. (1982). *Vision.* New York: Freeman.

Marslen-Wilson, W. D. (1987). Functional parallelism in spoken word-recognition. *Cognition, 25,* 71–102.

Massaro, D. W. (1979). Letter information and orthographic context in word perception. *Journal of Experimental Psychology: Human Perception and Performance, 5,* 595–609.

Masson, M. E. J. (1991). A distributed memory model of context effects in word identification. In D. Besner & G. W. Humphreys (Eds.), *Basic processes in reading: Visual word recognition* (pp. 233–263). Hillsdale, NJ: Erlbaum.

McClelland, J. L. (1987). The case for interactionism in language processing. In M. Coltheart (Ed.), *Attention and performance XII: The psychology of reading* (pp. 3–36). Hillsdale, NJ: Erlbaum.

McClelland, J. L. (1991). Stochastic interactive processes and the effect of context on perception. *Cognitive Psychology, 23,* 1–44.

McClelland, J. L., & Rumelhart, D. E. (1981). An interactive model of context effects in letter perception. Part 1. An account of basic findings. *Psychological Review, 88,* 375–407.

McQueen, J. M. (1991). The influence of the lexicon on phonetic categorization: Stimulus quality in word-final ambiguity. *Journal of Experimental Psychology: Human Perception and Performance, 17,* 433–443.

Meyer, D. E., & Schvaneveldt, R. W. (1971). Facilitation in recognizing pairs of words: Evidence of a dependence between retrieval operations. *Journal of Experimental Psychology, 90,* 227–234.

Miller, G. A., Heise, G., & Lichten, W. (1951). The intelligibility of speech as a function of the context of the test materials. *Journal of Experimental Psychology, 41,* 329–335.

Morris, R. K., Rayner, K., & Pollatsek, A. (1990, November). *Semantic context effects on fixation time in reading.* Paper presented at the Annual Meeting of the Psychonomic Society, New Orleans, LA.

Morton, J. (1969). The interaction of information in word recognition. *Psychological Review, 76,* 165–178.

Norris, D. (1986). Word recognition: Context effects without priming. *Cognition, 22,* 93–136.

O'Seaghdha, P. G. (1989). The dependence of lexical relatedness effects on syntactic connectedness. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 15,* 73–87.

Paap, K. R., McDonald, J. E., Schvaneveldt, R. W., & Noel, R. W. (1987). Frequency and pronounceability in visually presented naming and lexical decision tasks. In M. Coltheart (Ed.), *The psychology of reading. Attention and performance XII* (pp. 221–243). Hillsdale, NJ: Erlbaum.

Paap, K. R., Newsome, S. L., McDonald, J. E., & Schvaneveldt, R. W. (1982). An activation-verification model for letter and word recognition: The word-superiority effect. *Psychological Review, 89,* 573–594.

Phillips, W. A. (1974). On the distinction between sensory storage and short-term visual memory. *Perception & Psychophysics, 16,* 283–290.

Pollack, I., & Pickett, J. M. (1964). Intelligibility of excerpts from fluent speech: Auditory versus structural context. *Journal of Verbal Learning and Verbal Behavior, 3,* 79–84.

Potter, M. C. (1982, November). *Very short-term memory: In one eye and out the other.* Paper presented at the Annual Meeting of the Psychonomic Society, Minneapolis, MN.

Potter, M. C. (1984). Rapid serial visual presentation (RSVP): A method for studying language processing. In D. Kieras & M. Just (Eds.), *New methods in reading comprehension research* (pp. 91–118). Hillsdale, NJ: Erlbaum.

Potter, M. C. (1990, November). *Word selection in reading sentences: Preceding versus following context.* Paper presented at the Annual Meeting of the Psychonomic Society, New Orleans, LA.

Potter, M. C., Kroll, J. F., Yachzel, B., Carpenter, E., & Sherman, J. (1986). Pictures in sentences: Understanding without words. *Journal of Experimental Psychology: General, 115,* 281–294.

Potter, M. C., & Noel, A. (1987, November). *Conversion of nonwards* [sic] *to words in RSVP.* Paper presented at the Annual Meeting of the Psychonomic Society, Seattle, WA.

Ratcliff, R., McKoon, G., & Verwoerd, M. (1989). A bias interpretation of facilitation in perceptual identification. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 15,* 378–387.

Reicher, G. M. (1969). Perceptual recognition as a function of meaningfulness of stimulus material. *Journal of Experimental Psychology, 81,* 275–280.

Rueckl, J. G., & Oden, G. C. (1986). The integration of contextual and featural information during word identification. *Journal of Memory and Language, 25,* 445–460.

Samuel, A. G. (1981). Phonemic restoration: Insights from a new methodology. *Journal of Experimental Psychology: General, 110,* 474–494.

Simpson, G. B., Peterson, R. R., Casteel, M. A., & Burgess, C. (1989). Lexical and sentence context effects in word recognition. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 15,* 88–97.

Stone, G. O., & Van Orden, G. C. (1989). Are words represented by nodes? *Memory & Cognition, 17,* 511–524.

Swinney, D. A. (1979). Lexical access during sentence comprehension: (Re)consideration of context effects. *Journal of Verbal Learning and Verbal Behavior, 18,* 645–659.

Vanderwart, M. (1984). Priming by pictures in lexical decision. *Journal of Verbal Learning and Verbal Behavior, 23,* 67–83.

Warren, R. M., & Warren, R. P. (1970). Auditory illusions and confusions. *Scientific American, 223*(6), 30–36.

Wheeler, D. D. (1970). Processes in word recognition. *Cognitive Psychology, 1,* 59–85.

Whittlesea, B. W. A., & Jacoby, L. L. (1990). Interaction of prime repetition with visual degradation: Is priming a retrieval phenomenon? *Journal of Memory and Language, 29,* 546–565.

Williams, J. N. (1988). Constraints upon semantic activation during sentence comprehension. *Language and Cognitive Processes, 3,* 165–206.

Zwitserlood, P. (1989). The locus of the effects of sentential-semantic context in spoken-word processing. *Cognition, 32,* 25–64.

(Appendixes follow on next page)

Appendix A

Examples of Materials Used in Experiment 2

The slot in biased sentences (a and b) was filled in different versions by the biased-against word and the nonword; the slot in the neutral sentence (c) was filled by both words and the nonword. The priming words used in Experiment 3 are italicized.

1. Bench, bunch, bonch
   a. The *defendant* sat on the ________ during the *trial.*
   b. The *grape* lover devoured the ________ during *breakfast.*
   c. Nina told me she *saw* the ________ near the *counter.*
2. Park, pork, purk
   a. The children.love to *play* at the ________ by the *stream.*
   b. The *butcher* usually sells the ________ for a high *price.*
   c. After nine o'clock on *weekdays* the ________ is *free.*
3. Stamp, stump, stimp
   a. When I addressed the *letter* I put a ________ on the upper *corner.*
   b. When the men cut down the *tree* I found a ________ on the side of the *road.*
   c. When I *opened* my eyes I saw a ________ on the *corner.*
4. Belly, bully, bally
   a. The *overweight* man had a big ________ and red *cheeks.*
   b. All the children *feared* the big ________ and his *brother.*
   c. You would not believe the *size* of the ________ that we *saw.*
5. Stare, store, sture
   a. The woman gave the *bum* a ________ when he entered the *room.*
   b. The woman *bought* dresses at a ________ when on *vacation.*
   c. The woman *noticed* the man's ________ when she *walked* down the street.
6. Diet, duet, doet
   a. The *college* student survived on a ________ of *soda* and pretzels.
   b. The *pianist* and the flutist performed a ________ of superb *quality.*
   c. If *done* correctly a ________ can be very *enjoyable.*
7. Lace, lice, loce
   a. The wedding *dress* was white and had ________ on the *sleeves.*
   b. The orphan girl was *filthy* and had ________ in her *hair.*
   c. At the used *clothing* outlet many dresses had ________ in the *fabric.*
8. Sale, sole, sile
   a. Everyone in the department *store* was pleased with the ________ this *afternoon.*
   b. At the *seafood* restaurant the waiter served the ________ with *butter.*
   c. Everyone at the *market* was pleased with the ________ this *afternoon.*
9. Strap, strip, strup
   a. Since the *luggage* was so heavy its ________ *broke* at the airport.
   b. After shredding the *paper* I used a ________ to write a grocery *list.*
   c. The *pages* were held together by only a ________ of *leather.*
10. Tent, tint, tont
    a. Those four *boys* set up a ________ in the *backyard* last night.
    b. The *painter* used a ________ of *orange* in the portrait.
    c. My brother liked the *green* ________ best of all the *choices.*

Appendix B

Examples of Materials in Experiment 4

The first two sentences in each set are the *old* sentences, equivalent to those in Experiment 2 (Appendix A). The second two sentences are the *new* sentences in which sentence-level bias is switched to the other critical word.

1. Bench, bunch, bonch
   The defendant sat on the ________ during the trial.
   The grape lover devoured the ________ during breakfast in the garden.
   The defendant sat with his ________ during the trial.
   The grape lover devoured his breakfast on the ________ in the garden.
2. Park, pork, purk
   The children love to play and eat at the ________ by the stream.
   The butcher usually sells the ________ for a high price.
   The children who had been playing ate their ________ down by the stream.
   The butcher who sells near the ________ charges a high price.

3. Stamp, stump, stimp
   When I addressed the letter I put a ________ on the upper corner.
   When the men cut down the tree I found a ________ on the side of the road.
   After I addressed the letter I put it on the ________ by the corner.
   There was a picture of men cutting down a tree on the ________ I found by the side of the road.
4. Belly, bully, bally
   The overweight man had a big ________ and red cheeks.
   All the children feared the big ________ and his father.
   The overweight man was a big ________ and he had red cheeks.
   The children feared they would get their father's big ________ when they grew up.
5. Stare, store, sture
   The woman gave the bum a ________ when he entered the building.
   The woman bought dresses at a ________ when on vacation.
   The woman noticed the bum by the ________ when she entered the building.
   The woman who bought so many dresses drew a ________ from the other vacationer.
6. Diet, duet, doet
   The college student survived on a ________ of soda and pretzels.
   The pianist and the flutist performed a ________ of superb quality.
   The college student sat through the ________ with soda and pretzels.
   Before each performance the pianist and flutist go on a ________ of superb quality.
7. Lace, lice, loce
   The wedding dress was white and had ________ hidden in the sleeves.
   The orphan girl was filthy and had ________ in her hair.
   The white of the wedding dress kept her from noticing the ________ hidden in the sleeves.
   Although the orphan girl was filthy someone tied a piece of ________ in her hair.
8. Sale, sole, sile
   Everyone in the department store was pleased with the ________ this afternoon.
   At the seafood restaurant the waiter served the ________ with butter.
   Everyone was pleased because the department store gave away free samples of ________ this afternoon.
   At the seafood restaurant the waiter served whatever was on ________ without butter.
9. Strap, strip, strup
   The luggage was so full that it broke open when its ________ failed at the airport.
   From the bundle of shredded paper I used a ________ to write a grocery list.
   The luggage was so full that it broke open on the ________ at the airport.
   The bundle of shredded paper was held with a ________ for writing future grocery lists.
10. Tent, tint, tont
   The four boys set up a strange ________ under the trees last night.
   The painter used a green ________ in the portrait.
   The four boys spotted a strange ________ above the trees last night.
   The painter works outside that green ________ when he paints portraits.

Appendix C

Examples of Materials Used in Experiment 5

The first and third sentences in each set have discriminative context only after the critical stimulus.

1. Navel, novel, nevel
   If there is no ________ in an orange it will be dry.
   An orange will be dry if there is no ________ in it.
   If there is no ________ to publish the editor will be unhappy.
   The editor will be unhappy if there is no ________ to publish.
2. Tonic, tunic, tanic
   Because of the special ________ the bar served it was popular with locals.
   The bar that served the special ________ was popular with locals.
   Because of the special ________ the tailor embroidered he was famous among visitors.
   The tailor who embroidered the special ________ was famous among visitors.
3. Wasp, wisp, wesp
   She brushed the ________ aside because insects bothered her.
   Insects bothered her so she brushed the ________ aside.
   She brushed the ________ of her hair aside because it was in her eyes.
   Because her hair was in her eyes she brushed the ________ aside.
4. Sale, sole, sile
   She was pleased with the ________ at the dress shop on Columbus Day.
   The dress shop had a big ________ on Columbus Day that she went to.

She was pleased with the ________ at the fish market on Sunday.
The fish market had the ________ she wanted on Sunday.

5. Math, moth, meth
He liked the ________ class but failed the exam.
He failed the exam although he liked his ________ class.
He liked the ________ that flew around the light.
Around the light flew the ________ which he liked.
6. Rain, ruin, roin
We saw the ________ as it poured down and filled the gutters.
As it filled the gutter we watched the ________ pour down.
We saw the ________ in Athens on our trip to Greece.
On our trip to Greece we saw the ________ in Athens.
7. Watch, witch, wetch
With the ________ still ticking he knew it wasn't broken.
The ticking of the ________ showed that it wasn't broken.
With the ________ at the Halloween party, we took lots of pictures.
At the Halloween party the ________ took lots of pictures.
8. Stare, store, sture
While the ________ he gave her made her uncomfortable she ignored him.
She saw him looking at her with a ________ that made her uncomfortable.
While the ________ had its sale they hired extra employees.
During the sale the ________ hired extra employees.
9. Knack, knock, kneck
Because of her ________ for math we always asked for her help.
We always asked for her help in math because of her ________ for it.
Because of her ________ at the door I hung up the phone.
At the door there was a ________ so I hung up the phone.
10. Pimp, pump, pamp
I saw the ________ on the street in the Combat Zone with his pals.
On the street in the Combat Zone I saw the ________ and his pals.
I saw the ________ beside the bicycle and the spare tire.
Beside the bicycle I saw the ________ and the spare tire.

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