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Suppressing Irrelevant Information: Knowledge Activation or Inhibition?

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In 3 experiments, the authors examined the role of knowledge activation in the suppression of contextually irrelevant meanings for ambiguous homographs. In Experiments 1 and 2, participants with greater baseball knowledge, regardless of reading skill, more quickly suppressed the irrelevant meaning of ambiguous words in baseball-related, but not general-topic, sentences. Experiment 3 demonstrated that participants with greater general knowledge, regardless of reading skill, more quickly suppressed the irrelevant meaning of the ambiguous words in general-topic sentences. As predicted by D. S. McNamara's (1997) knowledge-based account of suppression, ambiguity effects are influenced by greater activation of knowledge related to the intended meaning of the homograph. These results challenge inhibition (e.g., M. A. Gernsbacher, K. R. Varner, & M. Faust, 1990) as the sole mechanism responsible for the suppression of irrelevant information.

Text and discourse present numerous challenges for the comprehender. One facet of communication that is particularly challenging is the resolution of lexical ambiguity. For example, homographs such as *bug, match, draft,* and *mold* have multiple meanings, and when these homographs are encountered, the comprehender must resolve the intended meaning of the word. Research has shown that when ambiguous words are presented, multiple meanings are initially activated regardless of the meanings' relevance to the sentence context (e.g., Kintsch & Mross, 1985; Swinney, 1979; cf. Simpson & Krueger, 1991). Research has further shown that skilled and less skilled comprehenders can be distinguished in terms of how quickly the irrelevant meaning of an ambiguous word loses activation (Gernsbacher & Faust, 1991; Gernsbacher, Varner, & Faust, 1990). For example, Gernsbacher et al. (1990) presented participants with experimental sentences ending with homographs, such as *He dug with a spade,* or control sentences, such as *He dug with a shovel,* followed by an inappropriate target word, *ACE,* for which the participant was to decide if it was related to the previous sentence. They found an ambiguity effect such that response times to reject the inappropriate word were slower for the homograph sentences than for the control sentences when the target word was presented after only 50 ms. Their result indicated that the activation of the irrelevant meaning of the sentence-final ambiguous word competed with the correct response. However, after a 1,000-ms delay, interference from the irrelevant meaning disappeared for skilled comprehenders but remained for less skilled comprehenders. They proposed that the ability to subdue interference from the irrelevant meaning of ambiguous words is a function of a suppression mechanism. That is, skilled comprehenders more efficiently suppress, or inhibit, the irrelevant meaning of the ambiguous word, whereas less skilled comprehenders lack such a mechanism. In this article, we follow this terminology such that *suppression* will refer to an operative mechanism that, when inefficient, is responsible for the ambiguity effect.

Gernsbacher et al.'s (1990) proposal was based on Gernsbacher's (1990) structure building model. Briefly, comprehension consists of three primary processes: (a) laying a foundation for the text or discourse structure, (b) mapping information onto that foundation, and (c) shifting to new structures when new information cannot map onto the existing structure because it is incongruent or it is the beginning of a new idea. Enhancement, which increases activation, and suppression, which decreases activation, are the two mechanisms that operate to determine the strength of memory nodes. Comprehension depends on the efficient construction and maintenance of mental structures. If new information is related to the current structure, then it is enhanced and incorporated into the mental structure. However, if new information is not related to the current structure, the comprehender may shift to a new mental substructure, or, alternatively, may suppress the new irrelevant information. The latter results in fewer substructures and reduces memory load for the comprehender. By this view, some comprehenders are less skilled because they have an inefficient suppression mechanism; with less effective suppression of irrelevant information, too many substructures are created and maintained, such that comprehension suffers.

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The Knowledge-Based Account

As an alternative to Gernsbacher's proposal, McNamara (1997) proposed a "knowledge-based" account of the suppression results (Gernsbacher & Faust, 1991; Gernsbacher et al., 1990). The knowledge-based account was grounded in Kintsch's (1988, 1998) construction-integration (CI) model of comprehension. According to the CI model of text comprehension (Kintsch, 1988, 1998), text-based and knowledge-based inferences result in more links between concepts and thus a more cohesive mental structure. Thus, activation of prior knowledge helps the reader form a more coherent mental representation of the text (e.g., McNamara, 2001; McNamara, E. Kintsch, Songer, & W. Kintsch, 1996; McNamara & W. Kintsch, 1996). Consequently, readers with more knowledge of the text domain (e.g., science or history) show better comprehension when they use their prior knowledge to comprehend and learn.

McNamara's (1997) account was also inspired by a large body of reading research showing that skilled comprehenders more actively process information than less skilled readers. In particular, skilled readers tend to generate inferences that repair conceptual gaps, whereas less skilled readers tend to ignore gaps and fail to make the necessary inferences (e.g., Long, Oppy, & Seely, 1994; Magliano, Wiemer-Hastings, Millis, Muñoz, & McNamara, 2002; Oakhill & Yuill, 1996; Oakhill, Yuill, & Donaldson, 1990). In addition, many studies have demonstrated advantages for text-induced active processing (e.g., Einstein, McDaniel, Owen, & Cote, 1990; McNamara, 2001; O'Brien & Myers, 1985). Essentially, comprehension is enhanced when readers are induced by the text to generate inferences and these inferences are successful. Thus, active inference generation, due to the reader's aptitudes or the environment, is tightly tied to comprehension.

An additional finding that apparently contradicts Gernsbacher's (1990) theory of lexical disambiguation skill emerges from research showing that skilled comprehenders are also more likely to comprehend riddles and jokes (e.g., Yuill, 1996). Understanding jokes clearly requires activating multiple senses of words and sentences. The question arises as to how skilled comprehenders might in one scenario activate alternative word meanings but in another scenario know to inhibit those meanings.

McNamara (1997) proposed that the results reported by Gernsbacher et al. (1990) could be explained more parsimoniously in terms of enhancement of relevant information rather than inhibition of irrelevant information. According to Kintsch's (1988, 1998) CI model, incoming information and associated knowledge are represented as an associative network of nodes (concepts, ideas, or propositions) and links (relations or actions). Concepts that are compatible with the overall context generally have more links, whereas irrelevant concepts tend to have fewer links. Following connectionist learning principles, concepts with more links increase in activation, whereas those with fewer links gradually lose activation.

McNamara (1997) reasoned that if skilled comprehenders activated more knowledge associated with the context provided in the sentence, then more links to the relevant meaning of the ambiguous word would be created and the irrelevant meaning would quickly lose activation. In support of that hypothesis, she demonstrated within a CI simulation that the number of activated associations to the relevant meaning predicted the rate of activation loss for the irrelevant meaning. In this model, skilled comprehenders were assumed to more actively process the information provided in the sentence, which in turn activated more relevant knowledge. These links essentially fed activation to the relevant meaning of the ambiguous word and led to a rapid deactivation of the irrelevant meaning. To simulate less skilled comprehenders, less associated knowledge was activated. The relevant meaning was rapidly activated to threshold leading to an accurate understanding of the sentence, but the irrelevant meaning retained enough below-threshold activation to interfere with processing when it was presented in the decision task.

Specifically, McNamara's (1997) CI simulation included two cycles: the first cycle, representing the comprehension of the sentence, and the second cycle, used to process the target word and the decision task (i.e., meaning–fit judgment). As shown in Figure 1, the comprehension of each sentence included a surface structure, a textbase, and a situation model (Kintsch, 1988). In an effort to simulate Gernsbacher et al. (1990), three networks were constructed to represent three levels of active processing during the sentence processing: low, medium, and high (see Figure 1). These networks differed in the amount of prior knowledge available in the situation model—skilled comprehenders activated the greatest amount of prior knowledge during sentence comprehension, thus providing an additional source of activation for the decision that the target (*ACE*) is not related to the preceding sentence. In this sense, only the enhancement of the appropriate meaning of the sentence had an effect on the response time for the decision, and there was no suppression mechanism to affect the outcome.

In the first cycle of the simulation, the mental representation of the sentence was integrated in parallel, yielding a final activation value for each of the concepts included in the representation. As shown in Figure 2A, the simulation of sentence comprehension accurately predicted that all three groups of participants would correctly interpret the sentence. In contrast, the predicted activation of the inappropriate interpretation, *ISA*(*SPADE,CARD*), was 0.198, 0.268, and 0.491 for skilled, medium-skilled, and less skilled comprehenders, respectively. Thus, although the appropriate interpretation was predicted to be equally enhanced for both groups of participants, the activation of the inappropriate interpretation was an inverse function of skill level.

The second cycle of the simulation (i.e., the decision task) included the textbase (i.e., *DIG*(*HE,SPADE,WITH*), the situation model, the target word (i.e., *ACE*), and the two decisions (i.e., related, not related). The crucial outcome of this simulation concerned the relative activation values for the two decisions. It was assumed that decision times would be a function of the number of iterations required and final activation levels. The time course of these activation levels (i.e., the outcome after each iteration of the simulation) is plotted in Figure 2A for the decision that *ACE* is not related and Figure 2B for the incorrect decision that *ACE* is related.

The network settled after 16, 26, and 70 iterations for the skilled, medium-skilled, and less skilled comprehenders, respectively. There was relatively equivalent activation of the decision that *ACE* was not related for the three groups. The activation of the incorrect decision that *ACE* was related (which would cause interference and slow response time) was high early in the process for the skilled comprehenders but dropped quickly. In contrast, for the medium-skilled comprehenders, the activation level of the incor-

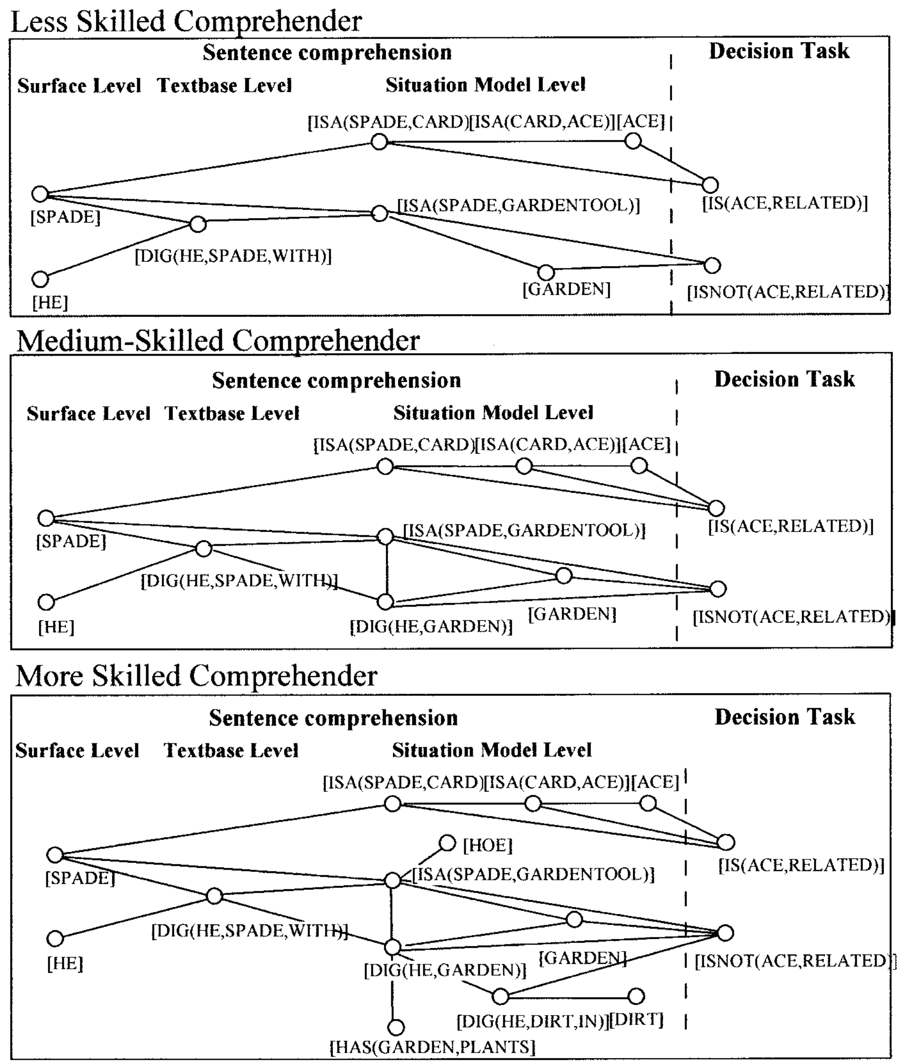

Figure 1. Less, medium-, and more skilled comprehenders' representations of the sentence *He dug with a spade,* followed by the decision task for whether the word *ACE* was related to the sentence. The three representations differ in the amount of prior knowledge activated in the situation model level of understanding.

rect decision was high early in the process but decreased more slowly. For the less skilled comprehenders, the incorrect decision that *ACE* was related was 1.00 across 11 iterations and dropped slowly to 0.041 after 70 iterations. This simulation thus correctly predicted that skilled comprehenders would show little interference from the inappropriate meaning of an ambiguous word only after a delay, whereas less skilled comprehenders would have slower responses for both the immediate and delayed tests.

Gernsbacher and Faust (1991) had concluded that their results were not a function of greater enhancement because skilled and less skilled comprehenders showed equivalent facilitation for the appropriate meaning (*GARDEN*) in a biased context, *He dug with a spade,* as compared with an unbiased context, *He picked up the spade.* However, McNamara's (1997) simulation showed that the differences between skilled and less skilled comprehenders emerged primarily from interference from the irrelevant meaning (for less skilled comprehenders) and not because of differences in facilitation. That is, the increase in associations to the appropriate meaning (for skilled comprehenders) had minimal effects on the time for the correct response to reach threshold. However, the increased associations in the skilled comprehender simulation essentially took over the network such that the irrelevant meanings more quickly died out. In contrast, in the less skilled comprehender simulation, the lack of competition for resources between relevant links and irrelevant links resulted in residual activation for the irrelevant meaning of the ambiguous word. Accordingly, less skilled comprehenders do not use resources effectively, whereas skilled comprehenders' maximal use of resources drives out irrelevant information.

Related Literature

The concept of inhibition pervades psychological theories and has done so from the beginning of this discipline (e.g., James,

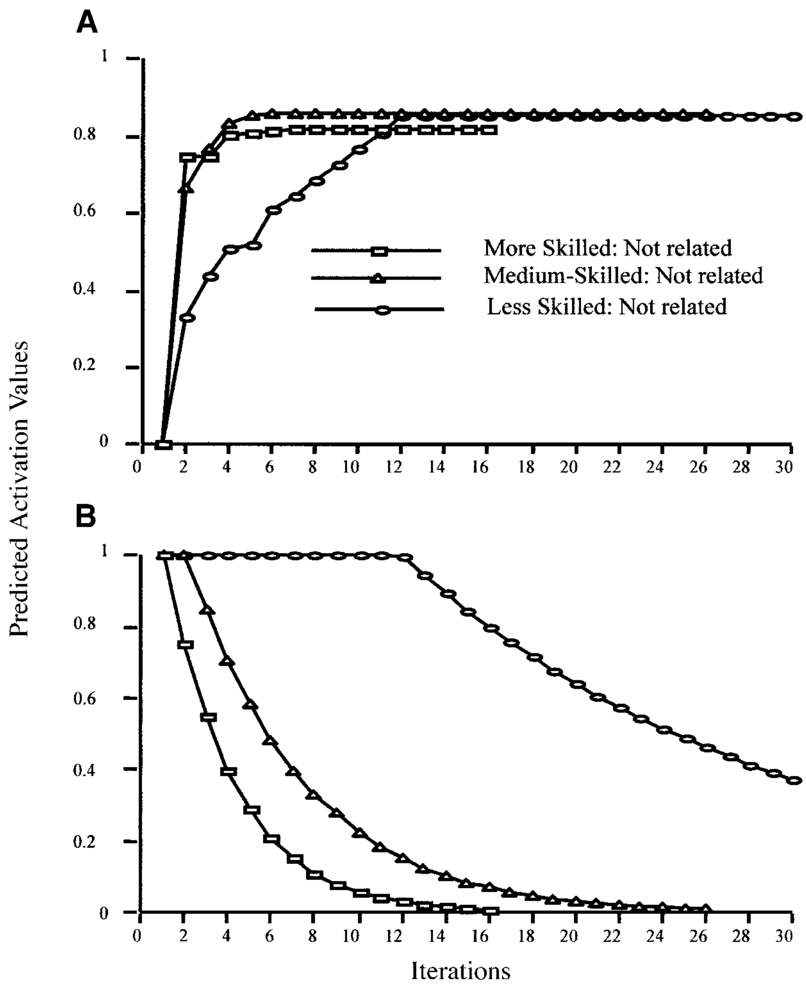

Figure 2. A: The predicted activation levels over time of the correct decision that *ACE* was not related to the sentence *He dug with a spade* for less, medium-, and more skilled comprehenders. B: The predicted activation levels over time of the incorrect decision that *ACE* was related to the sentence *He dug with a spade* for less, medium-, and more skilled comprehenders.

1890). The turn toward inhibition as a central construct within theories of the mind increased when physiological evidence for inhibition at the neuronal level became more widely accepted (e.g., Sherrington, 1906). As such, like Gernsbacher's (1990) model, many cognitive theories incorporate inhibition (e.g., repression, suppression) as an explanatory mechanism for behaviors that are impeded or delayed (e.g., M. C. Anderson, Bjork, & Bjork, 2000; Dagenbach & Carr, 1994; Dempster & Brainerd, 1995; Hasher, Zacks, & May, 1999; Tipper, 2001). However, it is important to note that inhibition at the neuronal level is not necessarily tied to cognitive functions. That is, the concept of inhibition at the neural level cannot be related directly to the concept of inhibition at the cognitive level. As MacLeod and his colleagues (MacLeod, Dodd, Sheard, Wilson, & Bibi, 2003) so aptly pointed out, "we would no more expect to find cognitive inhibition because there is neural inhibition than we would expect to find cognitive glia or cognitive ion channels because their neural counterparts demonstrably exist" (p. 165).

Furthermore, MacLeod et al. (2003) presented convincing empirical evidence that a wide variety of attention and memory phenomena involving decreased performance is not necessarily a signature of inhibition. They demonstrated that decreased memory performance can be more parsimoniously explained by routine memory retrieval processes coupled with the resolution of conflict between information available from memory and the present situation. Essentially, there is no conflict when an ongoing analysis is aligned with memory, and there is no need to make a choice. However, when automatic retrieval processes and current information diverge, then there is a need for a choice on the basis of conflict resolution, which takes time (for similar viewpoints, see, e.g., Jacoby, Debner, & Hay, 2001; Kahan, 2000; Logan, 2002; Neill & Mathis, 1998; Park & Kanwisher, 1994).

In the model proposed by McNamara (1997), the process of conflict resolution is hastened when the correct choice has an enriched representation. Larger time costs should be observed when both choices have relatively equivalent strengths, and both time costs and errors should be observed when the incorrect choice has a greater strength in memory. Long, Seely, and Oppy (1999) similarly proposed that the suppression effect was due to more strategic conflict resolution by skilled readers. They found that less skilled readers were more prone to interference than skilled readers but only when the test probe had an ambiguous relation to the preceding context and the task required context checking at test (i.e., lexical decision and meaning–fit judgments). They did not find a reading skill advantage for tasks that did not require context resolution (i.e., word naming).

McNamara's (1997) knowledge-based account of comprehension skill is also compatible with several (more detailed) theories of lexical disambiguation (e.g., Kawamoto, 1993). Specifically, lexical disambiguation models that incorporate both bottom-up and top-down processing correctly predict that both meaning dominance and context strength result in more rapid disambiguation (e.g., Duffy, Morris, & Rayner, 1988; Simpson & Krueger, 1991). For example, according to Kawamoto's connectionist account of lexical disambiguation, meaning dominance and context strength result in greater activation from lexical and semantic representations, respectively. These assumptions are consistent with McNamara's proposal that increased processing at the level of the situation model influences the resolution of ambiguity.

Hypotheses

The purpose of this study is to test a hypothesis that emerges from McNamara's (1997) account of the Gernsbacher (Gernsbacher & Faust, 1991; Gernsbacher et al., 1990) suppression results. This account predicts that when more associations are created that are relevant to the sentence context, the irrelevant meaning of ambiguous words should rapidly decrease. One factor that leads to the creation of more associations is greater domain knowledge. When a comprehender possesses more knowledge about a topic, more associations are generated during comprehension (e.g., J. R. Anderson, 1974). Therefore, readers with greater knowledge about a particular topic should show little or no ambiguity effect after a sufficient delay, whereas readers with low domain knowledge should exhibit significant ambiguity effects at those delays, regardless of their reading ability. Note that because these predicted differences in ambiguity effects are not based on the relative efficiency of a suppression mechanism, ambiguity effects should change for these same readers when the sentence domain changes.

In contrast, Gernsbacher's (1990) structure building model makes no assumptions regarding the efficiency of suppression in relation to domain knowledge, and, thus, by this model the presence of ambiguity effects should not necessarily be associated with domain knowledge. Instead, her model assumes that, if anything, the ambiguity effect should be driven by reading skill. We conducted three experiments to examine these predictions.

Experiment 1

One complicating factor associated with the knowledge-domain hypothesis is that those with greater knowledge tend to be better readers and vice versa. To this end, we first turned to a domain that seemed less related to reading skill than are many other domains—baseball. Several studies have demonstrated effects of knowledge on comprehension of baseball passages, regardless of reading ability (e.g., Spilich, Vesonder, Chiesi, & Voss, 1979). Therefore, we created sentences similar to those used by Gernsbacher et al. (1990) that were related to the topic of baseball and ended with ambiguous homographs (e.g., *The catcher wore a cup.*). We examined the latency to respond to a target word (*COFFEE*) that was presented 850 ms after each sentence, a delay sufficient to eliminate significant ambiguity effects for some readers (Gernsbacher et al., 1990). On the basis of McNamara's (1997) theoretical analysis, we hypothesized that for these sentences, readers with greater baseball knowledge would show no ambiguity effects but that readers with less baseball knowledge would exhibit significant ambiguity effects.

Though not predicted by a suppression-mechanism view, the above pattern would not necessarily be incompatible with such an interpretation. Accordingly, to further reveal the possible mechanism (or mechanisms) underlying these anticipated effects, we also presented participants with the general-topic sentences created by Gernsbacher et al. (1990). If the elimination of ambiguity effects on the baseball sentences for high-baseball-knowledge participants is related to a suppression mechanism, perhaps because of association of domain knowledge with reading ability, then these high-baseball-knowledge participants would be expected to also show no ambiguity effects for the general-topic sentences. If, on the other hand, the elimination of the ambiguity effects were related to the domain knowledge (cf. McNamara, 1997), then two patterns are possible. Both the high- and low-baseball-knowledge participants could show ambiguity effects, provided that their general knowledge does not promote sufficient activation of relevant information for the general-topic sentences; or, both groups could show no ambiguity effects if these participants' general knowledge promotes sufficient activation of relevant information.

To further disentangle possible suppression mechanisms from knowledge activation mechanisms, we also assessed participants' reading ability. We reasoned that if a suppression mechanism associated with reader's general ability were involved in the ambiguity effects, then analysis of the data as a function of reading ability should produce patterns that parallel those found in the primary analysis varying domain knowledge.

Method

Participants and design. One-hundred thirty-four undergraduate psychology students participated for course credit. Half of the participants were high in baseball knowledge and half were low. The levels of baseball knowledge were based on a median split for performance on a baseball knowledge test administered during the experiment. The 67 participants categorized as low-knowledge showed substantially worse performance on the knowledge test ($M = 3.58$, Min $= 0.0$, Max $= 6.0$, $SD = 1.60$) than those 67 assigned to the high-knowledge group ($M = 17.03$, Min $= 6.5$, Max $= 34.5$, $SD = 8.12$). Within each of these groups, approximately half (see Table 1 for N) were presented with sentences containing ambiguous words (i.e., homographs), and the remainder were presented with unambiguous sentences. Hence, level of baseball knowledge (high, low) and ambiguity (ambiguous, unambiguous) were between-subjects variables, and sentence genre (general, baseball) was a within-subjects variable.

Verification-task sentences. The total corpus of 188 four- to six-word sentences included 12 practice sentences (6 ambiguous, 6 unambiguous), 88 general-topic sentences, and 88 baseball sentences (see Appendix). The general-topic sentences, including 44 experimental sentences and 44 filler sentences, were obtained from the corpora used in Gernsbacher et al. (1990). Each experimental sentence had an ambiguous version (e.g., *He dug with a spade*) and an unambiguous version (e.g., *He dug with a shovel*). Probe words (e.g., *ACE*) were unrelated to the experimental sentences. Filler sentences ended with words that were related to the probe

Table 1
Mean Reaction Times in Experiment 1 as a Function of Baseball Knowledge, Sentence Genre, and Ambiguity

Baseball knowledge and ambiguity	Sentence genre	
	General	Baseball
High		
Ambiguous ($n = 33$)	1,059.69 (34.67)	961.79 (30.98)
Unambiguous ($n = 34$)	944.80 (24.00)	920.91 (22.74)
Difference (i.e., ambiguity effect)	114.89	40.88
	$F_1(1, 65) = 7.50$	$F_1 < 2$
	$F_2(1, 43) = 60.13$	$F_2(1, 43) = 5.04$
Low		
Ambiguous ($n = 34$)	1,204.75 (35.89)	1,141.31 (35.61)
Unambiguous ($n = 33$)	930.51 (23.86)	920.20 (21.53)
Difference (i.e., ambiguity effect)	274.24	221.11
	$F_1(1, 65) = 40.01$	$F_1(1, 65) = 27.83$
	$F_2(1, 43) = 169.68$	$F_2(1, 43) = 138.19$

Note. Mean standard errors are in parentheses.

word. For example, *He went to the office* was followed with the probe *JOB*. The correct response to any experimental sentence, be it ambiguous or unambiguous, was always "no," whereas the correct response to a filler sentence was always "yes." The computer randomly determined the order of sentence presentation.

An additional 44 experimental sentences and 44 filler sentences were added to these original sentences, which were related to baseball. Four- to six-word sentences were created that ended with either an ambiguous or an unambiguous word. The target word (e.g., *RING*) was related to the ambiguous word (e.g., *diamond*) but was related neither to the unambiguous sentence (e.g., *Baseball is played on a field*) nor to the ambiguous sentence (e.g., *Baseball is played on a diamond*). Participants in our first norming study were asked to rate on a 7-point Likert scale the relationships between the target words and both the ambiguous and unambiguous final words of the corresponding sentence. Unrelated word pairs (i.e., for control sentences) were retained if they had an average rating less than 2.5. Related word pairs were retained if they had an average rating greater than 4.5. A second norming study verified that participants did not consider the sentences to be related to the target words.

A third norming study was conducted to compare the general (i.e., from the Gernsbacher et al., 1990, corpora) and baseball materials in terms of degree of relatedness between the sentences and the target words and between the final words with the target words. Using a 7-point Likert scale, one group of 84 participants provided relatedness ratings (i.e., rating the degree of relationship) between each of the 176 sentences (including experimental sentences and fillers) and their corresponding target words, and another group of 86 participants provided relatedness ratings between the sentence-final words and the target words. Our first two goals were to verify that for both sets of sentences (i.e., baseball and general), participants rated (a) filler sentences as more related than experimental (ambiguous and unambiguous) sentences to the target words and (b) sentence-final ambiguous words as more related than sentence-final unambiguous words to the target words. Our third goal was to determine whether the baseball and general material sets differed in meaningful ways.

Average relatedness ratings are presented in Table 2. For all analyses reported, the rejection level was set as .05. Thus, p values are reported only for marginal results. First, our analyses confirmed that the relatedness ratings for filler sentences were significantly greater than both ambiguous sentences—baseball, $F(1, 83) = 1{,}321.69$, $MSE = 1.008$, and general, $F(1, 83) = 1{,}353.02$, $MSE = 1.141$—and unambiguous sentences—baseball, $F(1, 83) = 2{,}025.94$, $MSE = 0.862$, and general, $F(1, 83) = 2{,}386.03$, $MSE = 0.822$. Second, relatedness ratings for sentence-final ambiguous words were significantly greater than sentence-final unambiguous words—baseball, $F(1, 85) = 1{,}449.08$, $MSE = 0.380$, and general, $F(1, 83) = 1{,}638.37$, $MSE = 0.336$ (all ps $< .001$). Hence, both sets display the expected relationships between the sentences and words.

It is apparent from the means presented in Table 2 that the critical properties of the sentences relative to the targets were virtually identical for the newly constructed baseball materials and the general-topic materials from the Gernsbacher et al. (1990) corpora. Specifically, the baseball and general-topic sentences were both rated as being highly unrelated to the ambiguous word, with the degree of relatedness not significantly differing ($M_{\text{general}} = 1.94$, $M_{\text{baseball}} = 1.91$). As well, the final words of both sentence genres were rated as related to their respective ambiguous targets by the same magnitude ($M_{\text{general}} = 5.25$, $M_{\text{baseball}} = 5.16$). Ratings for the unambiguous targets were again quite similar across the two sets of materials, though statistical differences did emerge: word to target, $F(1, 85) = 6.46$, and sentence to target, $F(1, 85) = 6.66$. The most apparent rating differences across material sets were for the filler sentences, especially with the degree of relatedness of the final word to target: word to target, $F(1, 85) = 894.97$, and sentence to target, $F(1, 85) = 67.89$. This is not especially worrisome as the fillers are all intermixed during experimental presentation, and, moreover, the critical latency measures do not include filler items. The crucial outcome of the norming study was verification that the degree of relatedness for the baseball materials mirrored those of the general items.

Reading comprehension ability. Form H of the Nelson Denny Adult Reading Comprehension Test (Brown, Fishco, & Hanna, 1993) was used to assess general reading ability. This measure included a total of seven passages and 38 questions. The participants read a passage and then answered comprehension questions concerning each passage. The reader could refer back to the passage to answer the questions. The participants were administered the standardized instructions and given 20 min to complete the test.

Baseball Knowledge Test. A shortened version of the Baseball Knowledge Test created by Spilich et al. (1979) was used to establish knowledge specific to the domain of baseball. The test consisted of 36 short-answer questions related to Major League Baseball rules (e.g., "If the visiting team is ahead, how many innings must a game go to be official?"), terms (e.g., "What does RBI stand for?"), and strategy (e.g., "If a third baseman not noted for speed is playing deep at third base a batter may try to get to first base by ______?").

Procedure. Each trial began with a plus mark that appeared on the screen for 850 ms. The plus mark signaled the beginning of the trial and oriented the participant to where the sentence was then displayed. Each sentence appeared for 2,000 ms plus 33 ms per word (e.g., a four-word

Table 2
Mean Relatedness Ratings as a Function of Rating Type, Sentence Genre, and Ambiguity

Rating type and ambiguity	Sentence genre	
	General	Baseball
Sentence to target		
Ambiguous	1.937 (0.094)	1.913 (0.085)
Unambiguous	1.392 (0.058)	1.336 (0.059)
Filler	6.224 (0.060)	5.895 (0.071)
Sentence-final word to target		
Ambiguous	5.247 (0.074)	5.164 (0.078)
Unambiguous	1.671 (0.060)	1.585 (0.064)
Filler	6.072 (0.056)	4.663 (0.070)

Note. Mean standard errors are in parentheses.

sentence appeared for 2,132 ms). The probe word followed the presentation of the sentence after 850 ms. Participants had 2,500 ms to respond as to whether the target word was related to the sentence. The "?" key, which was colored green and labeled with a *y* represented the "yes" key, and the *x* key, which was colored red and labeled with an *n* represented the "no" key. The computer provided the participant immediate feedback concerning accuracy. Participants first completed 12 practice trials before beginning the 176 experimental trials. The sentence-verification task required approximately 20 min.

After completing the sentence-verification task, participants were given 20 min to complete the Nelson Denny Reading Comprehension Test. They were then given the Baseball Knowledge Test.

Results

Across all three experiments, participant (F_1) and item (F_2) analyses were conducted on the average correct reaction time to decide whether the target word was related to the sentence, with an inclusion criterion for a participant of 70% accuracy. All participants in Experiment 1 correctly responded to more than 70% of the sentences ($M = 92.3\%$). For *all analyses,* the rejection level was set at .05. In all experiments, we first report the primary analyses that involved the knowledge domain variable. Because reading skill and domain (baseball) knowledge were reliably correlated in several experiments (Experiment 1, $r = .23$, $p < .01$; Experiment 2, $r = .26$, $p = .06$; Experiment 3, $r = .24$, $p < .01$), we also conducted secondary analyses in which participants were regrouped according to reading skill to investigate whether reading skill per se produced the focal patterns associated with domain (baseball) knowledge.

A three-factor mixed analysis of variance (ANOVA) was conducted that included (in the participant analysis) the within-subjects variable of sentence genre (baseball, general) and the between-subjects variables of ambiguity (ambiguous, unambiguous) and baseball knowledge (low, high). The average reaction times as a function of sentence genre, ambiguity, and baseball knowledge are presented in Table 1. To facilitate presentation of the complex pattern of results, we first report basic effects associated with the materials and then focus on the critical effects involving baseball knowledge.

Sentence genre and ambiguity. There was a main effect of sentence genre, $F_1(1, 130) = 87.41$, $MSE = 1{,}831.170$, $F_2(1, 86) = 4.54$, $MSE = 45{,}396.990$; a main effect of ambiguity, $F_1(1, 130) = 31.92$, $MSE = 55{,}613.872$, $F_2(1, 86) = 223.91$, $MSE = 9{,}406.185$; and a reliable interaction between sentence genre and ambiguity, $F_1(1, 130) = 36.96$, $F_2(1, 86) = 12.79$. These results indicate that general-topic sentences were responded to more slowly than baseball sentences ($M_{\text{general}} = 1{,}035.530$, $M_{\text{baseball}} = 986.725$) and that ambiguous sentences resulted in slower responses to the probe than unambiguous sentences ($M_{\text{ambiguous}} = 1{,}093.097$; $M_{\text{unambiguous}} = 929.157$). The interaction indicates that the ambiguity effect was less robust (but reliable) for baseball sentences—$M_{\text{ambiguous}-\text{unambiguous}} = 131.00$, $F_1(1, 132) = 19.14$, $F_2(1, 43) = 73.32$—than for general-topic sentences—$M_{\text{ambiguous}-\text{unambiguous}} = 194.56$, $F_1(1, 132) = 39.16$, $F_2(1, 43) = 154.04$.

Baseball knowledge. There was a main effect of knowledge, $F_1(1, 130) = 7.22$, $F_2(1, 86) = 200.98$, $MSE = 2{,}718.60$; an interaction between knowledge and sentence genre, $F_1(1, 30) = 5.27$, $F_2(1, 86) = 6.94$); and an interaction between knowledge and ambiguity, $F_1(1, 30) = 8.68$, $F_2(1, 86) = 186.23$, $MSE = 3{,}140.61$. These results show that participants with more knowledge of baseball responded more quickly than low-knowledge participants ($M_{\text{low}} = 1{,}051.040$; $M_{\text{high}} = 971.214$). However, this advantage was significantly more robust for the baseball sentences than for the general-topic sentences. Finally, the interaction between knowledge and ambiguity indicates that there was a greater ambiguity effect for low-knowledge participants—$M_{\text{ambiguous}-\text{unambiguous}} = 247.681$, $F_1(1, 65) = 34.76$, $F_2(1, 86) = 307.518$—than for high-knowledge participants—$M_{\text{ambiguous}-\text{unambiguous}} = 77.888$, $F_1(1, 65) = 3.90$, $p = .053$, $F_2(1, 86) = 51.65$.

To more precisely evaluate the presence of ambiguity effects across knowledge levels, we conducted separate analyses on each sentence genre for high-knowledge and low-knowledge participants. It is important to note that for the general-topic sentences, both low-knowledge readers and high-knowledge readers showed reliable ambiguity effects (see Table 1 for *F* values). In contrast, for the baseball sentences, there was a reliable ambiguity effect for low-knowledge readers but little ambiguity effect for high-knowledge readers. That is, the critical predicted pattern emerged such that after the 850-ms delay, for the general-topic sentences, the high-knowledge participants showed interference from the ambiguous sentence, whereas for the baseball sentences, only the low-knowledge participants showed significant interference. Therefore, baseball knowledge allowed readers to deactivate the irrelevant meaning of the ambiguous word for baseball sentences (see Figure 3) but not for general-topic sentences. Further analyses verified that these effects remained reliable when reading skill was entered either as a covariate or categorical variable and that this effect did not interact with reading skill.

Reading skill. We were interested in seeing whether differential ambiguity effects would also emerge as a function of reading ability. Reading skill was identified on the basis of a median split ($M = 28.8$; $Mdn = 30.0$) for performance on the Nelson Denny

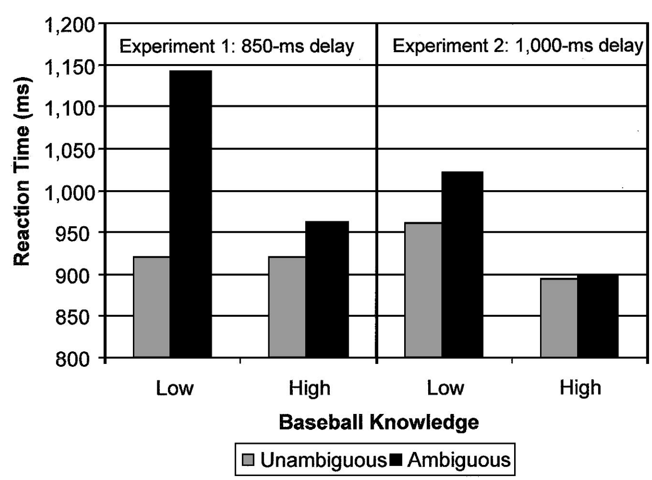

Figure 3. Reaction time to baseball sentences as a function of baseball knowledge and ambiguity in Experiments 1 and 2. There was a reliable ambiguity effect for participants with less knowledge about baseball, but not for high-knowledge participants, in both experiments.

reading test: 67 participants were categorized as less skilled (M = 24.00, Min = 11, Max = 29, SD = 4.91), and 67 participants were categorized as skilled (M = 33.69, Min = 30, Max = 38, SD = 2.20).[1] As would be expected because of random assignment, the ambiguous versus unambiguous groups did not reliably differ in terms of reading performance.

The results in terms of average reaction times as a function of reading skill, sentence genre, and ambiguity are presented in Table 3. A mixed three-factor ANOVA was conducted that included the within-subjects variable of sentence genre (baseball, general) and the between-subjects variables of ambiguity (ambiguous, unambiguous) and reading skill (less skilled, skilled).

The effects not tested by the primary ANOVA reported in the previous section were those that involved reading skill. There was a reliable effect of reading skill, $F_1(1, 130) = 9.15$, MSE = 57,426.979, $F_2(1, 86) = 212.99$, MSE = 3,055.088, and an interaction between reading skill and ambiguity that was significant according to the item analysis, $F_2(1, 86) = 74.51$, MSE = 2,316.076, but not according to the participant analysis, $F_1(1, 130) = 2.14$, $p = .146$. These results confirm that skilled readers responded to the probe significantly more quickly than less skilled readers ($M_{\text{less skilled}}$ = 1,066.026; M_{skilled} = 956.229). As expected, the by-items interaction reflects a greater ambiguity effect for less skilled participants—$M_{\text{ambiguous} - \text{unambiguous}}$ = 188.098, $F_1(1, 65) = 20.13$, MSE = 62,223.164, $F_2(1, 86) = 276.63$, MSE = 5,627.601—than for skilled participants—$M_{\text{ambiguous} - \text{unambiguous}}$ = 99.533, $F_1(1, 65) = 7.39$, MSE = 52,630.79, $F_2(1, 86) = 77.65$, MSE = 5,613.401).

Though skilled participants showed attenuated ambiguity effects, separate tests of the ambiguity effect for each skill level and sentence genre (see Table 3 for F values) indicated that ambiguity effects were present for both skill levels across both sentence genres. All of the differences were significant, with the exception of a marginally significant effect (according to the participant analysis; $p < .06$) on baseball sentences for skilled readers. An analysis of covariance revealed that this ambiguity effect was reliable when baseball knowledge was entered as a covariate, $F_1(1, 64) = 4.16$, MSE = 26,907.153. Furthermore, when baseball knowledge was included as a between-subjects variable in an analysis of the skilled readers and baseball sentences, there was a reliable interaction of knowledge and ambiguity, $F_1(1, 63) = 5.46$, MSE = 25,408.707. Specifically, there was a reliable ambiguity effect for low-knowledge (high-skilled) participants—$M_{\text{ambiguous} - \text{unambiguous}}$ = 211.584, $F_1(1, 24) = 8.99$, MSE = 27,569.463—but not for high-knowledge (high-skilled) participants ($M_{\text{ambiguous} - \text{unambiguous}}$ = 15.117; $F < 1$). Therefore, the elimination of ambiguity effects for baseball sentences was related to the underlying influence of baseball knowledge and not to reading skill.

Table 3
Mean Reaction Times in Experiment 1 as a Function of Reading Skill, Sentence Genre, and Ambiguity

Reading skill and ambiguity	Sentence genre: General	Sentence genre: Baseball
Skilled		
Ambiguous (n = 29)	1,059.16 (32.61)	976.66 (31.35)
Unambiguous (n = 38)	919.67 (28.49)	898.64 (27.39)
Difference (i.e., ambiguity effect)	139.49	78.02
	$F_1(1, 65) = 11.71$	$F_1(1, 65) = 3.71$*
	$F_2(1, 43) = 76.96$	$F_2(1, 43) = 14.34$
Less skilled		
Ambiguous (n = 38)	1,189.89 (28.49)	1,111.07 (27.39)
Unambiguous (n = 29)	961.45 (32.61)	948.28 (31.35)
Difference (i.e., ambiguity effect)	228.44	162.79
	$F_1(1, 65) = 24.99$	$F_1(1, 65) = 14.33$
	$F_2(1, 43) = 167.62$	$F_2(1, 43) = 109.02$

Note. Mean standard errors are in parentheses.
* $p = .058$; all other ps $< .01$.

Discussion

Experiment 1 demonstrated that baseball knowledge allowed the reader to suppress the irrelevant meaning of the ambiguous sentence-final word for the baseball sentences, regardless of reading skill. Readers with limited baseball knowledge could not suppress the irrelevant meaning of the ambiguous ambiguity after 850 ms, again regardless of reading skill. This differential ambiguity effect as a function of baseball knowledge for baseball sentences bears similarity to that found previously for general-topic sentences as a function of comprehension skill (Gernsbacher et al., 1990). Our findings, however, diverge from those reported by Gernsbacher et al. in a theoretically significant manner. In contrast to the Gernsbacher et al. effects with high-ability readers, participants with greater knowledge of baseball were not able to effectively suppress the irrelevant meanings of the general-topic sentences. This latter result verifies that it is not a general ability that enabled high-knowledge participants to more quickly suppress irrelevant meanings but rather one that is domain specific. Thus, the current findings suggest a different process from the suppression mechanism claimed to underlie the previous ambiguity effects obtained with comprehension skill and general-topic sentences (e.g., Gernsbacher et al., 1990).

Experiment 2

Because of the novelty of the results in Experiment 1, we repeated the experiment and additionally implemented several changes designed to expand the boundary conditions of the pattern. The present experiment attempted to demonstrate that the differential ambiguity effects associated with domain knowledge (for baseball sentences) would emerge with a longer delay of 1,000 ms, rather than 850 ms as used in Experiment 1. Finally, to rule out possible problems of sensitivity with regard to the ambiguity patterns in Experiment 1, we included in Experiment 2 ambiguity

[1] A median split rather than a tier split was used for this study so that more than one individual difference variable could be analyzed within certain analyses. For all analyses, it was verified that the conclusions remained the same regardless of how individual differences were defined (i.e., two categories, three categories, or as continuous variables within regression analyses). The data were analyzed using analyses of variance to more closely replicate the analyses used by Gernsbacher et al. (1990).

as a within-subjects variable rather than a between-subjects variable.[2]

Method

Participants and design. Fifty-two undergraduate psychology students participated for course credit. One participant did not meet the criterion for accuracy in the sentence probe task and was thus excluded from the analyses. Ambiguity (ambiguous, unambiguous) and sentence genre (general, baseball) were within-subjects variables. Baseball knowledge was a between-subjects variable, with 25 participants categorized as low knowledge (M = 3.7, Min = 0.0, Max = 6.0, and SD = 1.68 on the Baseball Knowledge Test), and 26 participants categorized as high knowledge (M = 15.0, Min = 7.0, Max = 30.5, and SD = 6.45).

Procedure materials. The general procedure was as described in Experiment 1, except that the delay between sentence presentation and the probe word was 1,000 ms, rather than 850 ms. The materials used for the sentence verification task, the Nelson Denny reading test, and the Baseball Knowledge Test were as described in Experiment 1. Two counterbalanced versions of the sentence-verification task were created, with the ambiguous form of a sentence in one version and the unambiguous form in the second version. Each test version included an equal number of four-, five-, and six-word sentences.

Results

Overall accuracy for the 51 participants meeting criterion was 94.8%. Reading skill and baseball knowledge were correlated at a level comparable to that in Experiment 1 (r = .26), but because of the lower number of participants, the value was not quite significant (p = .06).

A three-factor mixed ANOVA was conducted that included the within-subjects variables of sentence genre (baseball, general) and ambiguity (ambiguous, unambiguous) and the between-subjects variable of baseball knowledge (low, high). The results in terms of average reaction times as a function of baseball knowledge, sentence genre, and ambiguity are presented in Table 4.

Sentence genre and ambiguity. As in Experiment 1, there was a main effect of sentence genre, $F_1(1, 49) = 57.00$, MSE = 4,105.127; $F_2(1, 172) = 17.09$, MSE = 22,651.201; a main effect of ambiguity, $F_1(1, 49) = 43.80$, MSE = 4,644.083, $F_2(1, 172) = 13.65$, MSE = 22,651.201; and a reliable interaction between sentence genre and ambiguity, $F_1(1, 49) = 13.99$, MSE = 3,230.925; $F_2(1, 172) = 3.46$, MSE = 22,651.201, p = .065. These results indicate that general-topic sentences were responded to more slowly than baseball sentences (M_{general} = 1,010.850, M_{baseball} = 942.866) and that ambiguous sentences resulted in slower responses to the probe than unambiguous sentences ($M_{\text{ambiguous}}$ = 1,008.346; $M_{\text{unambiguous}}$ = 945.371). The interaction indicates that the ambiguity effect was less robust for baseball sentences—$M_{\text{ambiguous − unambiguous}}$ = 33.39, $F_1(1, 50) = 7.81$, $F_2 < 2$—than for general-topic sentences—$M_{\text{ambiguous − unambiguous}}$ = 92.94, $F_1(1, 50) = 48.05$, $F_2(1, 86) = 13.43$.

Baseball knowledge. There was a main effect of knowledge according to the by-items but not the by-participants analysis, $F_1(1, 49) = 2.46$, MSE = 140,742.953, $p < .15$, $F_2(1, 172) = 61.20$, MSE = 6,675.121. There was, in addition, a three-way interaction of baseball knowledge, ambiguity, and sentence genre, $F_1(1, 49) = 4.79$, MSE = 3,230.925; $F_2(1, 172) = 6.64$, MSE = 6,675.121.

Table 4
Mean Reaction Times in Experiment 2 as a Function of Baseball Knowledge, Sentence Genre, and Ambiguity

Baseball knowledge and ambiguity	Sentence genre: General	Sentence genre: Baseball
High knowledge (n = 26)		
Ambiguous	1,026.71 (40.13)	899.618 (33.84)
Unambiguous	926.13 (33.77)	893.439 (33.18)
Difference (i.e., ambiguity effect)	100.58	6.179
	$F_1(1, 25) = 23.32$	$F_{1,2} < 1$
	$F_2(1, 86) = 15.36$	
Low knowledge (n = 25)		
Ambiguous	1,089.30 (41.92)	1,021.36 (42.32)
Unambiguous	1,004.01 (40.16)	960.75 (43.56)
Difference (i.e., ambiguity effect)	85.29	60.61
	$F_1(1, 24) = 24.95$	$F_1(1, 24) = 11.29$
	$F_2(1, 86) = 6.04$	$F_2(1, 86) = 4.84$

Note. Mean standard errors are in parentheses.

Inspection of Table 4 shows that for baseball sentences, but not general-topic sentences, baseball knowledge influenced the magnitude of the ambiguity effect. Further analyses confirmed this interpretation of the three-way interaction. As shown in Figure 3, there was a reliable interaction between knowledge and ambiguity for baseball sentences, $F_1(1, 49) = 5.88$, MSE = 3,212.566; $F_2(1, 86) = 5.79$, MSE = 4,848.132. This interaction did not occur for the general-topic sentences, $F_1 < 1$, $F_2 < 2$. Further, both low-knowledge readers and high-knowledge readers showed a reliable ambiguity effect for the general-topic sentences (see Table 4 for F values). In contrast, for the baseball sentences, there was a reliable ambiguity effect for low-knowledge readers but no ambiguity effect for high-knowledge readers. Further analyses verified that the ambiguity effect for the baseball items was reliable for low-knowledge readers who were either skilled readers—$F_1(1, 11) = 6.16$, MSE = 3,653.125, $F_2(1, 86) = 5.69$, MSE = 20,376.216—or less skilled readers—$F_1(1, 12) = 4.89$, MSE = 4,786.942, $F_2(1, 86) = 2.00$, MSE = 19,328.571, p = .162—and was not reliable for high-knowledge readers who were either skilled or less skilled readers (all Fs < 1). Therefore, in support of Experiment 1's results, baseball knowledge allowed the reader to resolve the meaning of the ambiguous word for baseball sentences but not for general-topic sentences.

Reading skill. Reading skill was identified on the basis of a median split (M = 30.0, Mdn = 31.0) for performance on the Nelson Denny reading test: Twenty-five participants were categorized as less skilled (M = 26.0, Min = 11.0, Max = 30.0, SD = 4.50), and 26 participants were categorized as skilled (M = 33.9, Min = 31.0, Max = 37.0, SD = 1.69).

The average reaction times as a function of reading skill, sentence genre, and ambiguity are presented in Table 5. A three-factor mixed ANOVA (within-subjects variables of sentence genre and ambiguity and the between-subjects variable of reading skill)

[2] A between-subjects manipulation of ambiguity was used by Gernsbacher et al. (1990) and Gernsbacher and Faust (1991).

Table 5
Mean Reaction Times in Experiment 2 as a Function of Reading Skill, Sentence Genre, and Ambiguity

Reading skill and ambiguity	Sentence genre: General	Baseball
Skilled ($n = 26$)		
Ambiguous	1,018.57 (40.32)	927.92 (36.70)
Unambiguous	905.77 (38.17)	883.47 (37.73)
Difference (i.e., ambiguity effect)	112.08	44.44
	$F_1(1, 25) = 24.67$ $F_2(1, 86) = 10.75$	$F_{1,2} < 2$
Less skilled ($n = 25$)		
Ambiguous	1,097.77 (41.12)	1,002.15 (37.43)
Unambiguous	1,014.96 (38.92)	971.13 (38.48)
Difference (i.e., ambiguity effect)	82.81	31.02
	$F_1(1, 24) = 22.58$ $F_2(1, 86) = 10.23$	$F_1(1, 24) = 6.87$ $F_2 < 2$

Note. Mean standard errors are in parentheses.

failed to find any significant effects that involved reading skill. There was a tendency for less skilled readers to respond more slowly than skilled readers, $F_1(1, 49) = 2.80$, $MSE = 139{,}825.823$, $p = .10$; $F_2(1, 172) = 71.17$, $MSE = 7{,}466.595$ ($M_{\text{less skilled}} = 1{,}021.501$; $M_{\text{skilled}} = 933.932$). However, the interaction between reading skill and ambiguity did not approach significance ($F_1 < 2$, $F_2 < 1$), even when using only the top and bottom thirds in terms of reading skill ($F_{1,2} < 1$).

Separate tests for the ambiguity effect in each condition showed that the ambiguity effect was reliable in all cases, with the exception of a nonsignificant effect on baseball sentences for skilled readers (see Table 5 for *F* values). As in Experiment 1, however, this null effect was due to an underlying effect from baseball knowledge. That is, when baseball knowledge was included as a between-subjects variable, there was a reliable interaction of knowledge and ambiguity, $F_1(1, 24) = 5.59$, $MSE = 3{,}023.499$, $F_2(1, 86) = 2.09$, $MSE = 199{,}973.814$, $p = .152$. Specifically, there was a reliable ambiguity effect for low-knowledge (high-skilled) participants—$M_{\text{ambiguous} - \text{unambiguous}} = 61.255$; $F_1(1, 11) = 6.163$, $MSE = 3{,}653.125$, $F_2(1, 86) = 5.687$, $MSE = 20{,}376.216$—but not for high-knowledge (high-skilled) participants ($M_{\text{ambiguous} - \text{unambiguous}} = 11.086$; $F_{1,2} < 1$).

Discussion

Experiment 2 generally replicated the results of Experiment 1 with a longer delay and a within-subjects rather than between-subjects manipulation of sentence ambiguity. However, in Experiment 1, the item analysis, but not the participant analysis, yielded a reliable Reading Skill × Ambiguity interaction. This interaction is expected on the basis of findings reported by Gernsbacher et al. (1990). It is also predicted by both the suppression and knowledge-based accounts, albeit for different reasons. In contrast, Experiment 2 did not reveal such an interaction. That is, ambiguity resolution in Experiment 2 was not significantly related to reading skill, as measured by a standard test of reading ability (Nelson Denny). Also, it is important to note that although the interaction was reliable (by items) in Experiment 1, the ambiguity effect remained reliable and substantial for skilled readers. We revisit this issue in the Discussion section of Experiment 3.

Like Experiment 1, Experiment 2 demonstrated that baseball knowledge allows the reader to deactivate the irrelevant meaning of the ambiguous word when the sentence is related to baseball (i.e., eliminating the ambiguity effect) but not when the sentence is from a general topic. This pattern is inconsistent with an interpretation that rests on the idea that some readers (e.g., skilled readers) have an effective suppression mechanism, whereas other readers have an inefficient suppression mechanism (Gernsbacher et al., 1990). If a general suppression mechanism were involved, then the group of readers showing effective suppression (high-baseball domain readers, in this case) should do so consistently across all sentence topics. In this experiment, the deactivation of irrelevant information was not related to a general skill but instead was a function of the match between the knowledge of the reader and the topic of the sentences being processed.

The interpretation we favor is that deactivation of irrelevant information is a by-product of elaboration (activation) of topic-relevant information (Kintsch, 1988; McNamara, 1997). With regard to the present findings, the idea is that greater knowledge about a topic allows or promotes more extensive activation of relevant information, which results in a reduction of activation for irrelevant information. This framework leads to the unique prediction that it should be possible to significantly reduce the ambiguity effects for the general-topic sentences but not for the baseball sentences for a set of readers with high general knowledge. The next experiment examined this possibility.

Experiment 3

Experiments 1 and 2 demonstrated that baseball knowledge helped readers to reduce activation of the irrelevant meaning of the ambiguous sentence-final word for sentences relating to baseball. In this experiment, our goal was to examine the corollary—whether general knowledge would have a similar effect on performance for the general-topic questions. Specifically, if knowledge activation contributes to the resolution of word meaning, then readers with more knowledge about a variety of general topics (e.g., humanities, art, literature) should show more efficient suppression of irrelevant information for the general-topic sentences but not for baseball sentences (relative to readers with less general knowledge).

A second goal of Experiment 3 was to provide a more complete picture of whether the present effects reflected deactivation over time of irrelevant meanings by high-knowledge participants or, alternatively, simply no initial activation of the irrelevant meanings by high-knowledge participants. To address this issue, we examined performance after 50 ms and after a 1,000-ms delay. If the irrelevant meaning was never activated by high-knowledge readers, then the ambiguity effect should be absent at both intervals. If high-knowledge participants more efficiently deactivated the irrelevant meaning because of knowledge activation over time, then there should be an ambiguity effect at the immediate test but not after the delay.

Method

Participants and design. One-hundred forty-six undergraduate psychology students participated for course credit. Delay (immediate, delayed), ambiguity (ambiguous, unambiguous), and sentence genre (general, baseball) were within-subjects variables. In separate analyses, participants were either divided into groups based on general knowledge (high, low) or baseball knowledge (high, low).

Procedure and materials. The general procedure was as described in Experiments 1 and 2. The delay between sentence presentation and the probe word was either 50 or 1,000 ms. The materials used for the verification-task sentences, the Nelson Denny reading test, and the Baseball Knowledge Test were as described in Experiments 1 and 2. However, to shorten the overall testing time (accommodating the General Knowledge Test), we gave participants 15 min (rather than 20 min) to complete the Nelson Denny reading test. In addition, participants were administered the General Knowledge Test described below.

General Knowledge Test. A General Knowledge Test was used to test knowledge across a variety of domains. The tests consisted of 20 multiple-choice questions taken from published test banks (e.g., Graduate Management Admission Test [GMAT]). Five possible answers were given for each question. Questions were assembled from a variety of areas such as literature (e.g., "A 20th century novel which made the public aware of the plight of migrant workers is ______"), history (e.g., "At the end of the Civil War, the vast majority of freed slaves found work as ______"), biology (e.g., "A process which can only take place in living cells containing chlorophyll is ______"), and several other areas. Participants were given 10 min to complete the test and were instructed to guess when unsure of an answer.

Results

Two participants in Experiment 3 did not meet the criterion for accuracy (and were excluded from the analyses). Overall accuracy for the remaining participants was 95.1%. A third participant was identified as an outlier in terms of average reaction time (M = 1,676.61) and was also excluded from the analyses. General knowledge was significantly correlated with both reading skill ($r = .57$, $p < .001$) and baseball knowledge ($r = .31$, $p < .001$); as in the previous experiments, reading skill and baseball knowledge were also correlated ($r = .24$, $p < .01$).

The data of primary interest regarded the effects of general knowledge (low, high). Accordingly, we first divided the participants into two groups based on a median split ($M = 9.64$; $Mdn = 10$) for performance on the General Knowledge Test. Sixty-eight participants were categorized as low knowledge ($M = 6.54$, Min = 1.0, Max = 9.0, $SD = 2.08$), and 75 participants were categorized as high knowledge ($M = 12.45$, Min = 10.0, Max = 16.0, $SD = 1.95$).

The results as a function of general knowledge are shown in Table 6. These data were submitted to a four-factor mixed ANOVA, with delay (immediate, delay); sentence genre (baseball, general); and ambiguity (ambiguous, control) as within-subjects variables and general knowledge (high, low) as the between-subjects variable.

Delay, sentence genre, and ambiguity. There were reliable main effects of all three within-participant variables: delay, $M_{\text{immediate}} = 1{,}069.703$; $M_{\text{delayed}} = 1{,}024.195$; $F_1(1, 141) = 65.72$, $MSE = 8{,}951.44$; $F_2(1, 168) = 13.42$, $MSE = 13{,}484.186$; sentence genre, $M_{\text{baseball}} = 1{,}019.822$; $M_{\text{general}} = 1{,}074.076$; $F_1(1, 141) = 99.56$, $MSE = 8{,}567.362$; $F_2(1, 168) = 19.49$, $MSE = 13{,}484.186$; and ambiguity, $M_{\text{unambiguous}} = 1{,}018.360$; $M_{\text{ambiguous}} = 1{,}075.538$; $F_1(1, 141) = 126.71$, $MSE = 7{,}557.995$; $F_2(1, 168) = 21.73$, $MSE = 13{,}484.186$. There were also reliable interactions between sentence genre and ambiguity—$F_1(1, 141) = 43.96$, $MSE = 7{,}076.718$, $F_2(1, 168) = 7.64$, $MSE = 13{,}484.186$—and sentence genre, ambiguity, and delay—$F_1(1, 141) = 7.94$, $MSE = 8{,}391.056$, $F_2(1, 168) = 1.91$, $MSE = 13{,}484.186$. The three-way interaction indicates that the ambiguity effect dissipated for the baseball sentences as a function of delay but did not for the general-topic sentences. Specifically, at the immediate presentation, the ambiguity effect was reliable for both baseball sentences—$M_{\text{ambiguous}-\text{unambiguous}} = 45.32$; $F_1(1, 141) = 20.61$, $MSE = 7{,}482.460$, $F_2(1, 42) = 5.67$, $MSE = 10{,}177.645$—and general-topic sentences—$M_{\text{ambiguous}-\text{unambiguous}} = 81.22$; $F_1(1, 141) = 58.06$, $MSE = 8{,}256.257$, $F_2(1, 42) = 12.07$, $MSE = 13{,}290.427$. At the delayed presentation, the ambiguity effect remained robust for the general-topic sentences—

Table 6
Mean Reaction Times in Experiment 3 as a Function of General Knowledge, Delay, Sentence Genre, and Ambiguity

	General			Baseball		
General knowledge and delay	Ambiguous	Control	Difference	Ambiguous	Control	Difference
High (n = 75)						
Immediate	1,116.49 (31.47)	1,041.88 (25.90)	74.61 $F_1(1, 74) = 26.47$ $F_2(1, 42) = 9.50$	1,037.40 (31.16)	995.35 (26.26)	42.05 $F_1(1, 74) = 8.65$ $F_2(1, 42) = 3.81$
Delayed	1,050.93 (29.70)	997.25 (27.85)	53.68 $F_1(1, 74) = 31.10$ $F_2(1, 42) = 7.65$	983.98 (28.11)	971.52 (25.71)	12.46 *ns*
Low (n = 68)						
Immediate	1,171.07 (26.09)	1,081.71 (23.71)	89.36 $F_1(1, 67) = 31.33$ $F_2(1, 42) = 10.76$	1,093.83 (24.52)	1,042.89 (24.31)	50.94 $F_1(1, 67) = 12.12$ $F_2(1, 42) = 4.66$
Delayed	1,152.27 (26.40)	1,026.09 (24.95)	126.18 $F_1(1, 67) = 61.20$ $F_2(1, 42) = 16.83$	1,024.75 (24.74)	1,030.56 (24.80)	−5.81 *ns*

Note. Differences = ambiguous − unambiguous; mean standard errors are in parentheses.

$M_{ambiguous-unambiguous}$ = 98.36; $F_1(1, 141) = 93.25$, MSE = 7,639.328, $F_2(1, 42) = 15.08$, MSE = 14,141.41—but essentially disappeared for the baseball sentences ($M_{ambiguous-unambiguous}$ = 3.81; $F_{1,2} < 1$).

General knowledge. The predicted interaction of general knowledge, sentence genre, and ambiguity approached significance, $F_1(1, 141) = 3.70$, MSE = 7,076.718, $p < .06$, $F_2(1, 168) = 2.76$, MSE = 2,915.142, $p < .10$. As predicted, general knowledge did not affect processing of the baseball sentences. In contrast, for general-topic sentences, there was a significant interaction of ambiguity and general knowledge, $F_1(1, 141) = 4.81$, MSE = 8,378.718, $F_2(1, 84) = 4.30$, MSE = 3,032.030. As shown in Table 6, this latter interaction reflects a smaller ambiguity effect for participants with high-general-knowledge ($M_{ambiguous-unambiguous}$ = 64.14) than for low-knowledge participants ($M_{ambiguous-unambiguous}$ = 107.77).

General knowledge and reading skill. Further analyses indicated that the effects of general knowledge interacted with reading skill for general-topic sentences. The response times for general-topic sentences as a function of reading skill, knowledge, delay, and ambiguity are presented in Table 7. There was an effect of knowledge by items, $F_2(1, 168) = 7.67$, MSE = 9,394.53, which was not reliable by participants, $F_1 < 1$. There was also an effect of reading skill: $M_{less\ skilled}$ = 1,127.885; $M_{skilled}$ = 1,053.249; $F_1(1, 139) = 3.71$, MSE = 180,583.768, p = .056, $F_2(1, 168)$ = 172.98, MSE = 7,407.96. These effects were modified by a reliable interaction between reading skill and knowledge: $F_1(1, 139) = 4.20$, $F_2(1, 168) = 115.551$. This two-way interaction reflected a reliable difference between skilled (M = 995.301) and less skilled readers (M = 1,149.306) with high knowledge—$F_1(1, 73) = 7.63$, MSE = 207,162.027, $F_2(1, 168) = 451.42$, MSE = 3,892.242—but not for those with low knowledge—$M_{less\ skilled}$ = 1,106.464; $M_{skilled}$ = 1,111.197; $F_1 < 1$; $F_2(1, 168) = 9.15$, MSE = 8,287.117.

However, this two-way interaction was modified by a reliable four-way interaction between reading skill, general knowledge, delay, and ambiguity, $F_1(1, 139) = 3.97$, MSE = 7,380.051, $F_2(1, 168) = 4.69$, MSE = 4,771.39. As shown in Figure 4, at the immediate test, there was a three-way interaction, $F_1(1, 139)$ = 4.90, MSE = 8,046.386, $F_2(1, 84) = 9.71$, MSE = 4,022.436. As shown in Table 7, the three-way interaction indicates that skilled readers with high general knowledge show small amounts of interference from the irrelevant meaning, even at the immediate test. The combined aptitudes apparently contributed to an ability to primarily process the relevant meaning of the ambiguous word. Of importance, at the delayed test, the ambiguity effect was lower for participants with greater general knowledge, regardless of reading skill. That is, the level of the ambiguity effect after the delay varied as a function of knowledge, $F_1(1, 139) = 5.51$, MSE = 7,773.201, $F_2(1, 84) = 4.82$, MSE = 9,156.600, not as a function of reading skill, $F_{1,2} < 1$.

Baseball knowledge. We next analyzed the data as a function of baseball knowledge (low, high). A median split (M = 10.48; Mdn = 8) for performance on the Baseball Knowledge Test resulted in 69 participants categorized as low knowledge (M = 3.10, Min = 0.0, Max = 6.0, SD = 1.69) and 74 participants categorized as high knowledge (M = 17.36, Min = 8.0, Max = 35.0, SD = 7.01). Here, we report only the effects associated with the baseball knowledge variable. The effect of baseball knowledge was significant by items, $F_2(1, 168) = 69.57$, MSE = 4,023.10, but not by participants, $F_1(1, 141) = 2.39$, MSE = 358,014.555; moreover, the interaction of sentence genre and baseball knowledge was nearly significant, $F_1(1, 141) = 3.58$, MSE = 8,406.872, p = .06, $F_2(1, 168) = 3.43$, MSE = 4,023.10, p = .06. Accordingly, a separate analysis was conducted on baseball sentences. Focusing on the effects related to baseball knowledge, high-knowledge participants tended to produce faster responses than low-knowledge participants: M_{low} = 1,054.922; M_{high} = 989.925, $F_1(1, 141) = 3.44$, MSE = 175,397.213, $p < .07$, $F_2(1, 84)$ = 57.66, MSE = 3,624.61. The interaction between knowledge and ambiguity was marginal, $F_1(1, 141) = 2.83$, MSE = 6,138.444, $p < .10$, $F_2 < 2$. Nevertheless, as found in Experiments 1 and 2,

Table 7
Mean Reaction Times in Experiment 3 to General-Topic Sentences as a Function of Reading Skill, General Knowledge, Delay, and Ambiguity

	High knowledge			Low knowledge		
Skill and delay	Ambiguous	Control	Difference	Ambiguous	Control	Difference
Skilled (HK, n = 50; LK, n = 19)						
Immediate	1,054.48 (33.97)	1,002.05 (29.45)	52.43 $F_1(1, 49) = 11.12$ $F_2(1, 42) = 3.79$*	1,170.07 (55.11)	1,054.90 (47.77)	115.17 $F_1(1, 18) = 11.84$ $F_2(1, 42) = 7.31$
Delayed	1,001.64 (33.29)	923.03 (31.01)	78.61 $F_1(1, 49) = 27.65$ $F_2(1, 42) = 7.90$	1,170.20 (54.00)	1,049.62 (50.31)	120.59 $F_1(1, 18) = 18.06$ $F_2(1, 42) = 6.17$
Less skilled (HK, n = 25; LK, n = 49)						
Immediate	1,240.51 (48.04)	1,121.54 (41.65)	118.97 $F_1(1, 24) = 17.41$ $F_2(1, 42) = 17.10$	1,171.45 (34.32)	1,092.11 (29.75)	79.34 $F_1(1, 48) = 19.47$ $F_2(1, 42) = 7.84$
Delayed	1,149.51 (47.07)	1,085.67 (43.86)	63.84 $F_1(1, 24) = 5.85$ $F_2(1, 42) = 3.57$*	1,145.32 (33.62)	1,016.97 (31.33)	128.35 $F_1(1, 48) = 42.62$ $F_2(1, 42) = 17.46$

Notes. Differences = ambiguous − unambiguous; mean standard errors are in parentheses. HK = high knowledge; LK = low knowledge.
* $p < .07$. All other ps $< .05$.

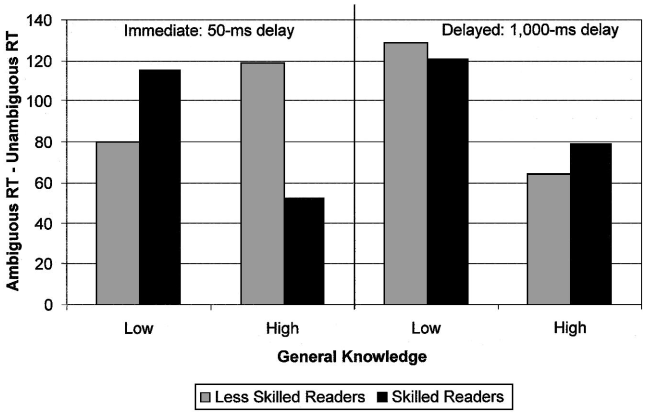

Figure 4. The ambiguity effect (i.e., ambiguous RT − unambiguous RT) as a function of general knowledge, reading skill, and delay. Skilled readers with high knowledge show a reduced ambiguity effect at the immediate test. At the delayed test, only high-knowledge readers, regardless of skill level, show a reduced ambiguity effect. RT = reaction time.

there was a significant ambiguity effect for low-knowledge participants—$M_{\text{ambiguous}-\text{unambiguous}}$ = 36.44, $F_1(1, 68) = 11.82$, $MSE = 7{,}750.096$, $F_2(1, 84) = 3.26$, $MSE = 8{,}656.27$—as compared with a reduced ambiguity effect for high-knowledge participants—$M_{\text{ambiguous}-\text{unambiguous}} = 14.39$, $F_1(1, 73) = 3.30$, $MSE = 4{,}637.179$, $p = .07$, $F_2 < 1$. Therefore, baseball knowledge helped participants to resolve the meaning of the sentence, resulting in less interference from the ambiguous word. As in the previous experiments, when reading skill was included, these results were not modified.

The separate analyses shown in Table 8 reveal reliable ambiguity effects in all cases except the delayed target presentations for the baseball sentences. High-knowledge participants showed a small but significant ambiguity effect at the immediate presentation, which disappeared after the delay. Low-knowledge participants showed a stronger ambiguity effect at immediate presentation than did high-knowledge participants. However, in contrast to Experiments 1 and 2, the low-knowledge participants did not show an ambiguity effect at the delayed presentation. Including reading skill in the analysis did not change these patterns.

Discussion

Several new results emerged from Experiment 3. First, general knowledge affected the magnitude of the ambiguity effect for general-topic sentences but not for the baseball sentences. Moreover, after the delay, the magnitude of the ambiguity effect for general-topic sentences was reduced for high-knowledge participants, whereas it was not affected by reading ability. These results, along with the companion findings for baseball knowledge effects in Experiments 1 and 2, converge on the theoretical notion that knowledge plays an important role in disambiguation. However, it is notable that across all three experiments, none of our participants were ever able to completely escape the interference effects imposed by the ambiguous words in the general-topic sentences. In Experiment 3, we found that ambiguity effects for general-topic sentences were reduced over time as a function of general knowledge, but never eradicated.

Second, low-baseball-knowledge participants showed greater ambiguity effects at the immediate test than did high-baseball-knowledge participants. Nevertheless, irrelevant meanings of ambiguous words were initially activated by the high-knowledge participants. This latter result confirms that participants with greater baseball knowledge experienced initial activation of the irrelevant meaning of the ambiguous word, which was deactivated over time. However, one unexpected and puzzling finding occurred for low-baseball-knowledge participants. In contrast to Experiments 1 and 2, these participants did not show significant ambiguity effects for baseball items after the delay. We speculate that requiring participants to respond to both immediate and delayed probes could have produced some carry-over artifacts. For instance, the presence of the immediate presentation condition may have induced participants into faster processing of delayed items.

Third, we found combined benefits of reading skill and general knowledge. Participants with both aptitudes showed overall faster

Table 8
Mean Reaction Times in Experiment 3 as a Function of Baseball Knowledge, Delay, Sentence Genre, and Ambiguity

	General			Baseball		
Knowledge and delay	Ambiguous	Control	Difference	Ambiguous	Control	Difference
High (N = 74)						
Immediate	1,120.86 (29.12)	1,043.58 (25.05)	77.28 $F_1(1, 73) = 42.40$ $F_2(1, 42) = 8.99$	1,024.40 (26.54)	995.75 (25.30)	28.65 $F_1(1, 73) = 5.53$ $F_2 < 2$
Delayed	1,075.13 (28.09)	977.44 (27.01)	97.69 $F_1(1, 73) = 56.21$ $F_2(1, 42) = 11.49$	969.84 (25.93)	969.71 (24.03)	0.13 *ns*
Low (N = 69)						
Immediate	1,165.58 (29.39)	1,079.32 (24.89)	86.26 $F_1(1, 68) = 22.21$ $F_2(1, 42) = 8.21$	1,106.95 (29.89)	1,041.77 (25.56)	65.18 $F_1(1, 68) = 15.77$ $F_2(1, 42) = 6.67$
Delayed	1,124.85 (29.52)	1,025.18 (26.13)	99.67 $F_1(1, 68) = 34.91$ $F_2(1, 42) = 12.10$	1,039.33 (27.04)	1,031.64 (26.68)	7.69 *ns*

Notes. Differences = ambiguous − unambiguous. Mean standard errors are in parentheses.

reaction times to the targets. In addition, these participants initially showed lower ambiguity effects than did other participants. Apparently, the combined aptitudes led to more efficient processing of the ambiguous word at the immediate interval. However, at the delayed interval, only general knowledge had reliable effects. Greater general knowledge led to less interference from the irrelevant meaning, regardless of reading ability. In turn, those with less general knowledge showed substantial interference, regardless of reading ability.

General Discussion

In the past decade, a handful of experiments have reported individual differences in the degree to which readers deactivate the irrelevant meaning of ambiguous words (e.g., Gernsbacher & Faust, 1991; Gernsbacher et al., 1990; Long et al., 1999). Up to now, the primary individual difference factor examined in published work on ambiguity resolution has been general comprehension skill as assessed by a comprehension battery developed by Gernsbacher and colleagues (Gernsbacher & Varner, 1990; cf. Long et al., 1999). Similarly, the primary theoretical orientation to explaining individual differences in deactivation of irrelevant meanings has posited a mechanism assumed to be intimately involved in differences in comprehension skill: a suppression mechanism for deactivating irrelevant meaning and interpretations. At the outset of this article, we raised another theoretical possibility: Deactivation of irrelevant meanings of ambiguous words could be related to activation of domain knowledge during the course of comprehension, instead of or in addition to a general suppression mechanism (McNamara, 1997). Motivated by this more recent theoretical approach to ambiguity effects, the primary purpose of this study was to examine the effects of domain knowledge on the resolution of ambiguity.

As predicated by McNamara's (1997) account, participants with more knowledge of baseball showed an effect of ambiguity for baseball sentences at the immediate test in Experiment 3 and the absence of an effect after delays of 850 ms (Experiment 1) and 1,000 ms (Experiment 2). In contrast, participants with less knowledge of baseball showed reliable ambiguity effects after delays in Experiments 1 and 2. Further, in Experiment 3, low-baseball-knowledge participants showed greater ambiguity effects at the immediate test than did high-baseball-knowledge participants. Thus, these results support the theoretical framework that individual differences in ambiguity resolution can depend on dynamics associated with knowledge activation during comprehension.

Zwaan and Truitt (2000) also examined effects of experience on the resolution of ambiguity. They hypothesized that smokers would have more densely integrated knowledge networks pertaining to smoking than nonsmokers. When nonsmokers and smokers read sentences such as *He couldn't play the match* followed by a word such as *LIGHTER,* they found that nonsmokers more quickly rejected the irrelevant words than did smokers. In contrast, the two groups performed similarly on Gernsbacher et al.'s (1990) general items. Note that Zwaan and Truitt's paradigm involved a fundamental difference from the current paradigm. In the current paradigm, the content of the sentences was related to the manipulated knowledge domain, whereas in Zwaan and Truitt the knowledge domain related to the relation between the final sentence word and the ambiguous target—not to the sentence itself. According to McNamara's (1997) account, smokers' knowledge would slow the decision-making process because of a greater strength and enhancement of the irrelevant meaning of the ambiguous word. The relative strength of the irrelevant meaning would interfere with recognition that this word was not related to the sentence. Thus, these results provide complementary support for the knowledge-based hypothesis. Whereas the present results show how knowledge may help suppress irrelevant information when the sentence content relates to the knowledge domain, the Zwaan and Truitt experiment shows how knowledge may interfere with effective suppression when the relationship between the sentence-final ambiguous word and the target articulates with the knowledge domain.

One might argue that these knowledge-based patterns reflect the operation of the kind of suppression mechanism presumed to underlie the interaction between comprehension skill and ambiguity effects reported in previous work (Gernsbacher et al., 1990). On this interpretation, suppression is a general mechanism that readers deploy effectively if the mechanism is intact or that readers cannot deploy if the mechanism is deficient. The present results counter this interpretation because the knowledge domain effects were systematically and predictably dependent on the content of the experimental sentences. Specifically, the pattern described above regarding baseball knowledge was limited to baseball sentences; these same groups of readers differing in baseball knowledge demonstrated no significant differences in the ambiguity effect for general content sentences in any of the three experiments. Complementing and reinforcing the pattern with baseball knowledge were the Experiment 3 findings with general background knowledge. Mirroring the effects of baseball knowledge, readers differing in general background knowledge significantly differed in the magnitude of ambiguity effects for general-content sentences but not for baseball sentences. Therefore, knowledge afforded readers the ability to deactivate the irrelevant meaning of the ambiguous words.

Another alternative interpretation might be that the elimination of ambiguity effects due to baseball knowledge for baseball but not general-topic sentences was somehow related to systematic differences across sentence sets in terms of the dynamics between the sentence constraints and the target words. For instance, if the baseball sentences were more constraining than general-topic sentences in terms of their relation to the ambiguous target or if the final words' relatedness to the ambiguous targets differed (across sentence sets), then ambiguity effects in baseball sentences might have been more easily eliminated because of high contextual constraints rather than high background knowledge. The ratings reported at the outset (Experiment 1), however, suggest that readers did not find the baseball sentences to be more constraining relative to general-topic sentences in terms of the sentences' relation to the ambiguous target. Both sentence sets were rated as unrelated to the ambiguous target and with virtually identical values (see Table 1). Nor was it the case that the final words in the sentences were viewed as noticeably more related to the ambiguous words for general sentences relative to baseball sentences (again, see Table 1). On the basis of these equivalencies in the ratings and the nondifferential effects of baseball knowledge on general-topic sentences and general knowledge on baseball sentences, this kind of "material-discrepancy" explanation of the findings seems unlikely. Further, the generality of the results beyond the particular sentence sets used in the study is reinforced in all three experiments with the parallel effects shown by the analyses by sentences (as the random variable) and the analyses by participants. These points notwithstanding, for some undetermined reason, baseball sentences were consistently responded to more quickly than general-topic sentences and were associated with less robust ambiguity effects.

With regard to reading ability, we also found limited evidence for what might be a general suppression mechanism in this study. When individual differences with regard to reading skill were examined, there were few direct relations between reading ability and the ambiguity effect. Nor does it appear to be the case that reading skill played a significant role in the emergence of the knowledge-domain effects, perhaps through mediation of knowledge activation. For instance, some theories propose that skilled readers have greater working-memory capacity than less skilled readers (e.g., Just & Carpenter, 1992): With more capacity, a reader may be able to activate more domain-related information than a less skilled reader with less capacity. The effects of baseball domain knowledge clearly did not depend on reading skill, however. When reading skill was included in the analyses in Experiments 1 and 2, there were no interactions between reading skill and domain knowledge. That is, there was no significant ambiguity effect for high-baseball-knowledge readers (for baseball sentences), regardless of reading skill, and, similarly, the ambiguity effect was significant for low baseball knowledge regardless of reading skill.

The effects of general knowledge on the magnitude of ambiguity effects after a delay for general-content sentences were also not dependent on reading ability. As can be seen in Figure 4, general knowledge alone seemed to be the key in terms of the resolution of ambiguity during a delay. For the delayed-target-presentation condition, skilled readers with low general knowledge showed ambiguity effects that were as robust as those displayed by less skilled readers with low knowledge. Further, both more skilled readers and less skilled readers with high knowledge showed similarly attenuated ambiguity effects. This latter result raises the possibility that the failure to find a reliable interaction between reading skill and ambiguity in Experiment 2 was due to knowledge differences that were not apparent using the Nelson Denny test. These results also further support the hypothesis that it is knowledge use that is key to comprehension skill.

The only hint that reading skill and domain knowledge may have jointly contributed to reduced activation of irrelevant meaning was for general domain knowledge at immediate testing (Experiment 3). Here, more skilled readers with more general knowledge showed a reduced initial activation of irrelevant meaning. Although potentially interesting, this effect does not speak to the present focus of the processes contributing to deactivation of irrelevant meanings over time.

Taken together, the current results converge on the conclusion that deactivation of irrelevant meanings is related to the presence and activation of relevant knowledge. The theoretical account that is most compatible with the present results is the knowledge activation explanation of ambiguity effects proposed by McNamara (1997). Within this account, disambiguation falls out of the structure of the connectionist-based model as a function of greater activation accruing to concepts relevant to the intended meaning than to irrelevant concepts. The relevant interlinked concepts in the network essentially consume activation within the constraint-satisfaction system. After a brief time, contextually irrelevant concepts lose activation; thus, their activation no longer slows response times to reject them as related to the sentence. Similar approaches have been implemented within the CI model to account for patterns of declining activation associated with other kinds of information involved in comprehension, such as predictive inferences (McDaniel, Schmalhofer, & Keefe, 2001; Schmalhofer, McDaniel, & Keefe, 2002).

In the context of this model, the present findings are likely reflective of an automatic knowledge activation process. That is, the participants with greater baseball knowledge automatically and unavoidably activated their knowledge of baseball when reading the baseball sentences. While knowledge activation was most likely the result of automatic processes in the experiments explored in the present study, knowledge activation can also be a more active, intentional process. For example, a large body of literature indicates that more skilled comprehenders more actively and strategically use knowledge than less skilled readers (e.g., Long et al., 1994; Magliano et al., 2002; Oakhill & Yuill, 1996). Along the same lines, when confronted with challenging material, a reader can be induced to activate and use knowledge more strategically (e.g., McNamara, 2001). Along similar lines, McNamara (in press) demonstrated that readers can be trained to more actively process text. When provided with training to use active reading strategies along with a technique called self-explanation (called SERT for Self-Explanation Reading Training), low-knowledge readers' comprehension scores were raised to levels equivalent to high-knowledge readers. Protocol analyses supported the conclusion that the readers had learned to use common knowledge and logic to make sense of low-coherence text. Thus, intentional, active knowledge use helps readers better comprehend written material.

On the basis of this assumption, our knowledge-based explanation of the present ambiguity effects can also account for the Gernsbacher and Faust (1991) findings that less able comprehenders failed to deactivate irrelevant meaning over the delay interval. Assuming that less skilled comprehenders are less strategic in activating relevant knowledge, then activation of irrelevant information would persist for these readers, thereby producing significant ambiguity effects over a delay. Thus, the Gernsbacher and Faust findings do not necessarily implicate a suppression mechanism that is deficient in less skilled comprehenders. Moreover, the interpretation that less skilled comprehenders are less likely to spontaneously engage in active text processing is favored by other related findings as well. McDaniel, Hines, and Guynn (2002) forced more active processing of text for skilled and less skilled comprehenders (assessed using the comprehension battery created by Gernsbacher & Varner, 1990) by scrambling the order of presentation of the sentences and requiring readers to reorder the sentences into a coherent text. Less skilled comprehenders, but not skilled comprehenders, consistently showed significantly more coherent representations (as indicated by improved free recall) for the scrambled- relative to an intact text condition. This pattern implies that less skilled comprehenders do not as actively engage in forming relevant linkages among information and must be pushed to engage in active, strategic processing of information in the text. Were less skilled comprehenders deficient in terms of a suppression mechanism, a pattern opposite of that reported by

McDaniel et al. (2002) would seem more plausible: More irrelevant interpretations would plausibly be suggested by scrambled text, which should produce deterioration of the coherence of the representation for comprehenders with a deficit suppression mechanism.

The results of these experiments clearly point to the importance of knowledge and knowledge activation for the resolution of ambiguity. Nevertheless, the results of these experiments do not rule out the possibility that a suppression mechanism may also be involved in ambiguity resolution. It remains to be seen whether ambiguity resolution effects associated with reading ability, as reported by Gernsbacher (Gernsbacher & Faust, 1991; Gernsbacher et al., 1990) and as found in Experiment 1, are mediated through a suppression mechanism or through the knowledge activation processes implicated in this study. However, the ability of the knowledge activation approach to straightforwardly account for the Gernsbacher and Faust (1991) results with skilled and less skilled comprehenders as well as the present results with readers differing in domain knowledge raises the possibility that a single knowledge-based activation process is sufficient to understand deactivation of irrelevant information during comprehension.

References

Anderson, J. R. (1974). Retrieval of propositional information from long-term memory. *Cognitive Psychology, 6,* 451–474.

Anderson, M. C., Bjork, R. A., & Bjork, E. L. (2000). Retrieval-induced forgetting: Evidence for a recall-specific mechanism. *Psychonomic Bulletin & Review, 7,* 522–530.

Brown, J., Fishco, V., & Hanna, G. (1993). *Manual for scoring and interpretation: Forms G & H.* Chicago: Riverside Press.

Dagenbach, D., & Carr, T. H. (Eds.). (1994). *Inhibitory processes in attention, memory, and language.* San Diego, CA: Academic Press.

Dempster, F. N., & Brainerd, C. J. (Eds.). (1995). *Interference and inhibition in cognition.* San Diego, CA: Academic Press.

Duffy, S. A., Morris, R. K., & Rayner, K. (1988). Lexical ambiguity and fixation times in reading. *Journal of Memory and Language, 27,* 429–446.

Einstein, G. O., McDaniel, M. A., Owen, P. D., & Cote, N. C. (1990). Encoding and recall of texts: The importance of material appropriate processing. *Journal of Memory and Language, 29,* 566–581.

Gernsbacher, M. A. (1990). *Language comprehension as structure building.* Hillsdale, NJ: Erlbaum.

Gernsbacher, M. A., & Faust, M. (1991). The mechanism of suppression: A component of general comprehension skill. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 17,* 245–262.

Gernsbacher, M. A., & Varner, K. R. (1990). *The multi-media comprehension battery* (Tech. Rep. No. 88-03). Eugene, Oregon: University of Oregon, Institute of Cognitive and Decision Sciences.

Gernsbacher, M. A., Varner, K. R., & Faust, M. (1990). Investigating differences in general comprehension skill. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 16,* 430–445.

Hasher, L., Zacks, R. T., & May, C. P. (1999). Inhibitory control, circadian arousal, and age. In D. Gopher & A. Koriat (Eds.), *Attention and performance XVII* (pp. 653–675). Cambridge, MA: MIT Press.

Jacoby, L. L., Debner, J. A., & Hay, J. F. (2001). Proactive interference, accessibility bias, and process dissociations: Valid subject reports of memory. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 27,* 686–700.

James, W. (1890). *The principles of psychology.* New York: Holt.

Just, M. A., & Carpenter, P. A. (1992). A capacity theory of comprehension: Individual differences in working memory. *Psychological Review, 99,* 122–149.

Kahan, T. A. (2000). Negative priming from masked words: Retrospective prime clarification or center–surround inhibition? *Journal of Experimental Psychology: Learning, Memory, and Cognition, 26,* 1392–1410.

Kawamoto, A. H. (1993). Nonlinear dynamics in the resolution of lexical ambiguity: A parallel distributed processing account. *Journal of Memory and Language, 32,* 474–516.

Kintsch, W. (1988). The use of knowledge in discourse processing: A construction-integration model. *Psychological Review, 95,* 163–182.

Kintsch, W. (1998). *Comprehension: A paradigm for cognition.* Cambridge, MA: Cambridge University Press.

Kintsch, W., & Mross, E. F. (1985). Context effects in word recognition. *Journal of Memory and Language, 8,* 336–344.

Logan, G. D. (2002). An instance theory of attention and memory. *Psychological Review, 109,* 376–400.

Long, D. L., Oppy, B. J., & Seely, M. R. (1994). Individual differences in the time course of inferential processing. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 20,* 1456–1470.

Long, D. L., Seely, M. R., & Oppy, B. J. (1999). The strategic nature of less skilled readers' suppression problems. *Discourse Processes, 27,* 281–302.

MacLeod, C. M., Dodd, M. D., Sheard, E. D., Wilson, D. E., & Bibi, U. (2003). In opposition to inhibition. In B. H. Ross (Ed.), *The psychology of learning and motivation, Vol. 43* (pp. 163–214). San Diego, CA: Academic Press.

Magliano, J. P., Wiemer-Hastings, K., Millis, K. K., Muñoz, B. D., & McNamara, D. S. (2002). Using latent semantic analysis to assess reader strategies. *Behavior Research Methods, Instruments, and Computers, 34,* 181–188.

McDaniel, M. A., Hines, R. J., & Guynn, M. J. (2002). When text difficulty benefits less-skilled readers. *Journal of Memory and Language, 46,* 544–561.

McDaniel, M. A., Schmalhofer, F., & Keefe, D. (2001). What is minimal about predictive inferences? *Psychonomic Bulletin & Review, 8,* 840–846.

McNamara, D. S. (1997). Comprehension skill: A knowledge-based account. *Proceedings of the Nineteenth Annual Meeting of the Cognitive Science Society* (pp. 508–513). Hillsdale, NJ: Erlbaum.

McNamara, D. S. (2001). Reading both high-coherence and low-coherence texts: Effects of text sequence and prior knowledge. *Canadian Journal of Experimental Psychology, 55,* 51–62.

McNamara, D. S. (in press). SERT: Self-explanation reading training. *Discourse Processes.*

McNamara, D., Kintsch, E., Songer, N., & Kintsch, W. (1996). Are good texts always better?: Interactions of text coherence, background knowledge, and levels of understanding in learning from text. *Cognition and Instruction, 14,* 1–43.

McNamara, D. S., & Kintsch, W. (1996). Learning from texts: Effects of prior knowledge and text coherence. *Discourse Processes, 22,* 247–288.

Neill, W. T., & Mathis, K. M. (1998). Transfer-appropriate processing: Negative priming and related phenomena. In D. L. Medin (Ed.), *The psychology of learning and motivation: Advances in research and theory* (Vol. 38, pp. 1–44). San Diego, CA: Academic Press.

Oakhill, J., & Yuill, N. (1996). Higher order factors in comprehension disability: Processes and remediation. In C. Cornaldi & J. Oakhill (Eds.), *Reading comprehension difficulties: Processes and intervention* (pp. 69–92). Mahwah, NJ: Erlbaum.

Oakhill, J., Yuill, N., & Donaldson, M. (1990). Understanding of causal expressions in skilled and less skilled text comprehenders. *British Journal of Developmental Psychology, 8,* 401–410.

O'Brien, E. J., & Myers, J. L. (1985). When comprehension difficulty improves memory for text. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 11,* 12–21.

Park, J., & Kanwisher, N. (1994). Negative priming for spatial locations: Identity mismatching, not distractor inhibition. *Journal of Experimental Psychology: Human Perception and Performance, 20,* 613–623.

Schmalhofer, F., McDaniel, M. A., & Keefe, D. (2002). A unified model for predictive and bridging inferences. *Discourse Processes, 33,* 105–132.

Sherrington, C. S. (1906). *The integrative action of the nervous system.* New Haven, CT: Yale University Press.

Simpson, G. B., & Krueger, M. A. (1991). Selective access of homograph meanings in sentence context. *Journal of Memory and Language, 30,* 627–643.

Spilich, G. J., Vesonder, G. T., Chiesi, H. L., & Voss, J. F. (1979). Text processing of domain-related information for individuals with high and low domain knowledge. *Journal of Verbal Learning and Verbal Behavior, 18,* 275–290.

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

Tipper, S. P. (2001). Does negative priming reflect inhibitory mechanisms? A review and integration of conflicting views. *Quarterly Journal of Experimental Psychology: Human Experimental Psychology, 54*(A), 321–343.

Yuill, N. (1996). A funny thing happened on the way to the classroom: Jokes, riddles, and metalinguistic awareness in understanding and improving poor comprehension in children. In C. Cornaldi & J. Oakhill (Eds.), *Reading comprehension difficulties: Processes and intervention* (pp. 193–220). Mahwah, NJ: Erlbaum.

Zwaan, R. A., & Truitt, T. P. (2000). Inhibition of smoking-related information in smokers and nonsmokers. *Experimental and Clinical Psychopharmacology, 8,* 192–197.

Appendix

Sentences and Target Words

Sentence	Target	Sentence	Target
	Experimental sentences		
Baseball related		General (Gernsbacher et al., 1990)	
He joined the ball club (team).	STICK	He ate a roll (muffin).	OVER
He pitched in the pros (yard).	WRITE	He ate a stalk (piece).	HUNT
He slid into the plate (wall).	DISH	He built the shed (shack).	HAIR
He swung with his bat (hand).	CAVE	He calculated the mass (length).	CHURCH
He threw to the short stop (girl).	SIGN	He dug with the spade (shovel).	ACE
He tossed the ball (mitt).	DANCE	He had a set (bunch).	PUT
He warmed up in the bullpen (side).	COW	He heard the ring (sound).	FINGER
He was the starting pitcher (catcher).	GLASS	He helped to seal (close).	ANIMAL
He was their first pick (choice).	PLUCK	He liked to row (swim).	COLUMN
Her ball was a foul (toy).	SMELL	He liked to watch (see).	TIME
His team scored a run (point).	STOCKINGS	He resisted the draft (war).	BEER
It was a double play (scoop).	THEATER	He shot with the bow (gun).	TIE
She got her third strike (start).	HURT	He smoked the pot (cigar).	PAN
She ran to the base (player).	BOTTOM	He talked to the sage (prophet).	BRUSH
She threw to left field (man).	WHEAT	He taught his pupils (eye).	EYE
That last pitch was outside (fast).	MOUNTAIN	He used all of his charm (wit).	BRACELET
The ball was thrown (white).	KING	He used the mug (goblet).	ROB
The ball went into the stands (air).	ERECT	He walked on the deck (tile)	CARDS
The ball went over the fence (wall).	SWORD	He won the match (title).	FIRE
The bases were loaded (full).	GUN	She attended the mass (funeral).	WEIGHT
The catcher caught the fly (toss).	BUG	She began to plot (scheme).	LAND
The catcher made a bad throw (decision).	RUG	She began to shed (drop).	WOOD
The catcher wore a cup (jersey).	COFFEE	She caught the bass (trout).	DRUM
The catcher wore his mask (pants).	HALLOWEEN	She did not want to sink (trip).	KITCHEN
The coach signaled to steal (go).	THIEF	She drank the draft (booze).	ARMY
The game was in the park (rink).	CAR	She expected the press (media).	IRON
The manager gave a signal (instruction).	TRAFFIC	She had a date (appointment).	FRUIT
The pitcher gave up a walk (hit).	STROLL	She helped the seal (dolphin).	SHUT
The pitcher started his move (windup).	VAN	She jabbed with the tip (end).	WAITER
The player got a run (an award).	JOG	She lit the match (lamp).	TENNIS
The player hit a grand slam (ball).	POUND	She picked up the rock (pebble).	MUSIC
The player made a hit (error).	FIST	She put on the ring (necklace).	BELL
The runner slid into home (third).	HOUSE	She sat on the perch (ledge).	FISH
The team needed a sweep (win).	BROOM	She started to gag (cough).	JOKE
The team played well (today).	WATER	She tried to jerk (yank).	FOOL
The umpire called her out (name).	IN	She tried to stalk (corn).	CORN
The umpire called her safe (coach).	LOCK	She turned to the right (left).	WRONG
The umpire made a call (correction).	PHONE	She used to bowl (ski).	CEREAL
The umpire's call seemed fair (correct).	CARNIVAL	She wanted to check (discover).	MONEY
There was a bunt (coach).	CAKE	She washed the china (crystal).	COUNTRY
They won that round (game).	SHAPE	She went to a quack (dentist).	DUCK
They won the title (fight).	BOOK	She went to the temple (sanctuary).	HEAD
Those players were the defenders (champions).	TRIAL	She wore the slip (nightgown).	SLIDE
Baseball is played on a diamond (field).	RING	She wrapped the present (package).	PAST

(*Appendix continues*)

Appendix (*continued*)

Sentence	Target	Sentence	Target
Filler sentences			
Baseball (sports) related		General (Gernsbacher et al., 1990)	
He called the player safe.	UMPIRE	He crossed the stream.	BROOK
He dove and hit the wall.	OUTFIELDER	He did the job poorly.	BAD
He is on the team.	PLAYER	He fried the meat.	COOK
He made it to the pros.	MAJORS	He had a dog.	PET
He played at short stop.	POSITION	He had a friend.	PAL
He sharpened his skills.	PRACTICE	He had the flu.	SICK
He stepped up to the plate.	READY	He had the jewel.	GEM
He threw out the man.	REFEREE	He heard the opera.	SING
He threw the football.	PASS	He left a book.	TEXT
He walked on the trail.	HIKE	He liked to listen.	HEAR
He was protected by the mask.	FACE	He liked to sleep.	NAP
He went to the ball park.	FIELD	He lived in the house.	HOME
He went to the beach.	SURF	He played with the thought.	IDEA
I rooted for the defenders.	FAN	He prepared the argument.	DEBATE
It was hit out of play.	FOUL	He shot with a camera.	PICTURE
She was their best pick.	CHOICE	He started the mower.	LAWN
The ball was low and outside.	AWAY	He talked to the boss.	SPEAK
The ball was not hit.	MISS	He tried a bite.	CHEW
The ball was ruled fair.	GOOD	He wanted to chuckle.	LAUGH
The boy wore a cup.	PROTECTION	He wanted to fib.	LIE
The coach argued the decision.	CALL	He went to the office.	JOB
The coach liked the umpire's call.	RULING	He went to the village.	TOWN
The game was ready to start.	BEGIN	She attended the school.	CLASS
The game went fast.	QUICK	She began to shiver.	COLD
The man made the throw.	CATCH	She began to spin.	WHIRL
The outfielder missed the fly.	BALL	She climbed the branch.	LIMB
The player finally got a run.	SCORE	She cooked in the stove.	OVEN
The player made an error.	MISTAKE	She drank the juice.	ORANGE
The player practiced his windup.	PITCHER	She expected the taxi.	CAB
The player put on his mitt.	GLOVE	She had to answer.	REPLY
The player ran to third.	BASE	She had to hide.	CONCEAL
The player rounded third for home.	PLATE	She hated the movie.	FILM
The player swung the bat.	HIT	She left to have lunch.	MEAL
The runner decided to go.	STEAL	She liked the flower.	ROSE
The team got their new pants.	UNIFORM	She sat on the sofa.	COUCH
The team had five girls.	FEMALE	She saw the rodent.	RAT
The team only had men.	MALE	She tried the dip.	SALSA
The team only had one run.	POINT	She turned on the blender.	MIX
The team won the award.	TROPHY	She walked through the door.	ENTER
The throw to first was correct.	RIGHT	She wanted to contribute money.	DONATE
The World Series was a sweep.	VICTORY	She wanted to stop.	QUIT
They were the champions.	WINNERS	She went to court.	TRIAL
They won by that steal.	SUCCESS	She went to shop.	BUY
This was his first grand slam.	RUN	She went to the dump.	GARBAGE

Note. Experimental sentences ended with either an ambiguous or a control word. Control words are in parentheses. The Gernsbacher sentences are from "Investigating Differences in General Comprehension Skill," by M. A. Gernsbacher, K. R. Varner, and M. Faust, 1990, *Journal of Experimental Psychology: Learning, Memory, and Cognition, 16,* pp. 430–445. Copyright 1990 by the American Psychological Association. Adapted with permission.

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