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Memory-Based Processing as a Mechanism of Automaticity in Text Comprehension

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A widespread theoretical assumption is that many processes involved in text comprehension are automatic, with automaticity typically defined in terms of properties (e.g., speed, effort). In contrast, the authors advocate for conceptualization of automaticity in terms of underlying cognitive mechanisms and evaluate one prominent account, the *memory-based processing* account, which states that one mechanism underlying automatization involves a shift from algorithm-based interpretation of stimuli to retrieval of prior interpretations of those stimuli. During practice, participants repeatedly read short stories containing novel conceptual combinations that were disambiguated with either their dominant or subordinate meaning. During transfer, the combinations were embedded in new sentences that either preserved or changed the disambiguated meaning. The primary dependent variable was reading time in the disambiguating region of target sentences. Supporting the memory-based processing account, speed-ups with practice were larger for repeated versus unrepeated items of the same type, reading times for subordinate versus dominant meanings of the combinations converged on later trials, and practiced meanings were retrieved when items appeared in a transfer context.

Keywords: text comprehension, automaticity, conceptual combination, instance theory

For many adults, text comprehension processes are usually fast and effortless. Skilled readers quickly and easily understand most of the text material they encounter in daily life. In short, text comprehension processes seem automatic to most of us. In accord with this intuitive description of text comprehension processes for skilled adult readers, a common theoretical assumption in comprehension research is that one or more of the specific processes involved in text comprehension have automatic components (e.g., Brown, Gore, & Carr, 2002; Flores d'Arcais, 1988; Hahne & Friederici, 1999; Kintsch, 1993; McKoon & Ratcliff, 1992; Perfetti, 1993; Rayner & Frazier, 1989; Singer, Graesser, & Trabasso, 1994; Walczyk, 2000).

An important question follows from these assumptions: What are the cognitive mechanisms that underlie the automatization of text comprehension processes? Although text comprehension skill is acquired over many years, skill acquisition involves many small incremental steps in improving the speed and accuracy with which various units of information can be processed. Given that different sets of cognitive mechanisms may be involved in the automatization of different kinds of learning tasks, the question at hand thus concerns the mechanisms that underlie these many small incremental improvements in text comprehension processes.

The goal of the present research was to investigate automaticity in text comprehension by exploring one mechanism, *memory-based processing*, which has been theorized to underlie the automatization of performance in various other cognitive tasks (Logan, 1988; Palmeri, 1997; Rickard, 1997). We begin by summarizing contemporary theories of automaticity, with particular emphasis on memory-based processing accounts. We next discuss the extent to which memory-based processing theories may provide a better understanding of automaticity in text comprehension. We then describe the particular comprehension process—conceptual combination—that will serve as our experimental fruit fly and explain why the examination of this process is particularly advantageous for present purposes.

Memory-Based Theories of Automaticity

In early automaticity theories, automatic processing was defined in terms of one or more properties of performance. For example, a cognitive process could be defined as automatic to the extent that it operated quickly, autonomously, and outside conscious awareness. Theories taking this approach to defining automaticity have been referred to as *property-list accounts* of automaticity (e.g., Hasher & Zacks, 1979; Schneider, Dumais, & Shiffrin, 1984; for a review of properties of performance associated with automaticity, see Moors & De Houwer, 2006). The main limitation of property-list accounts is that they are not explanatory—as Logan and Klapp (1991) stated, “Approaches that define automaticity in terms of manifest properties, such as speed, effortlessness, and autonomy (property-list approaches), are stipulative or descriptive but not predictive” (p. 179). These accounts may describe properties of performance before and after automatization, but they do not explain what underlies the transition and what gives rise to the properties of interest.

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Partly in response to the inherent limitations of earlier property-list accounts of automaticity, most contemporary theories have rejected the definition of automaticity in terms of properties and instead conceptualize automaticity in terms of underlying cognitive mechanisms. These accounts conceptualize the automatization of performance in a given task in terms of how underlying cognitive processes change with practice and assume that these changes in the underlying processes produce the observable properties of task performance. In other words, automaticity is defined in terms of cognitive mechanisms that explain properties of task performance, *not* in terms of the properties themselves. The property of task performance that mechanism-based accounts are most interested in explaining concerns the speed with which a task is performed. Indeed, speed-up in performance time with increasing practice is considered by many to be the signature pattern of automatization, and mechanism-based accounts of automaticity are primarily focused on explaining this robust effect.

To explain practice effects on performance time, several different kinds of cognitive mechanism have been posited. For example, Haider and Frensch (1996, 1999) have proposed an *information reduction* hypothesis, according to which individuals learn to focus attention on the task-relevant information and to ignore redundant information. As a result, task performance speeds up with practice because selective attention reduces the amount of information being processed. Alternatively, *algorithm efficiency* accounts assume that performance speeds up with practice because of improvements in the efficiency of the underlying algorithmic processes that interpret task stimuli. Theorists have proposed several mechanisms by which algorithm efficiency may be improved, most notably in versions of the ACT architecture (e.g., Anderson, 1982, 1987, 1996; Anderson & Lebiere, 1998). One of the primary mechanisms for improving algorithm efficiency in ACT-R involves tuning of subsymbolic parameters that regulate the likelihood of selecting effective productions and the speed with which selected productions fire.

Of greatest interest for present purposes, another class of automaticity theories posits that speed-ups with practice reflect a shift away from dependence on item-general algorithmic processes to increasing involvement of item-specific memory-based processing. According to *instance theory* (Logan, 1988), upon initial encounter of a stimulus, algorithmic processes generate an interpretation of that stimulus. This interpretation is then stored as an instance in long-term memory. On subsequent encounters of that stimulus, interpretation may be achieved either by the item-general algorithmic process (which can process all tokens of that type) or by retrieving a stored interpretation of the specific stimulus. The instance theory assumes that the algorithm and retrieval routes to interpretation race in parallel, with stimulus interpretation based on the output of whichever process finishes first. The theory also assumes that a separate instance is stored each time a stimulus is encountered and that instances race against one another to be retrieved. Assuming normally distributed retrieval times for each instance, the likelihood that at least one instance will be retrieved quickly increases with the number of instances in the race, and thus retrieval becomes more likely to finish before the algorithm. According to this theory, speed-ups with practice reflect a shift away from algorithmic processing to an increasing dependence on retrieval of prior interpretations. In other words, "Automaticity is memory retrieval: Performance is automatic when it is based on single-step direct-access retrieval of past solutions from memory" (Logan, 1988, p. 493). This is not to say that the algorithm necessarily drops out altogether. Depending on the relative speeds of the algorithm versus retrieval, the algorithm may still win the race on some proportion of trials (for relevant demonstrations, see the Monte Carlo simulation results reported by Logan, 1988). However, the main claim is that retrieval will win on an increasing number of trials as the number of stored instances increases.

More recently, other memory-based theories have been proposed (Rickard, 1997; Palmeri, 1997). Although these theories differ from instance theory in some auxiliary assumptions, all of these memory-based theories share the same core assumptions that are important for present purposes: Speed-ups with practice reflect decreasing involvement of algorithmic processing and increasing involvement of retrieval of prior interpretations of particular stimuli stored in long-term memory. These shared assumptions lead to several key predictions.

One prediction of memory-based processing accounts is that aspects of algorithm complexity that influence processing times early in practice will have a minimal influence on processing times later in practice. For example, Logan and Klapp (1991; Klapp, Boches, Trabert, & Logan, 1991) had participants practice an alphabet-arithmetic task in which they were to decide as quickly as possible whether equations were true (e.g., $A + 3 = D$) or false (e.g., $K + 2 = N$). At the beginning of practice, response time increased linearly with the magnitude of the digit addend (e.g., $A + 2$ was solved faster than $A + 3$). In contrast, at the end of practice, the linear slope was not significantly different than 0. At the beginning of practice, individuals computed the correct answer by counting up the alphabet from the letter addend, and equations requiring more counting steps took longer to compute than equations requiring fewer counts. By the end of practice, individuals presumably no longer counted up the alphabet but instead retrieved answers directly from long-term memory, and thus the magnitude of the digit addend no longer mattered.

Another key prediction of memory-based processing accounts is that speed-ups with practice will be greater for repeated stimuli than for novel stimuli of the same type. For example, Logan and Klapp (1991) repeatedly presented individuals with one set of alphabet-arithmetic equations during training, whereas another set of equations was only presented once at the end of training. Response times were significantly faster for repeated equations than for novel equations (see also Lassaline & Logan, 1993; Palmeri, 1997). These *item-specific practice effects* suggest that the speed-up with practice was due at least in part to the retrieval of prior interpretations of the repeated stimuli rather than to increased efficiency of item-general algorithmic processes. The item specificity of practice effects is particularly diagnostic of memory-based processing and one of the key ways in which the predictions of the memory-based processing accounts differs from others, in that several other accounts of automaticity predict item-general practice effects. For example, the information reduction hypothesis assumes that individuals learn which aspects of stimuli of a certain type are redundant, and so the reduction in the amount of information processed is not limited to repeated stimuli but to all tokens of that type. Similarly, algorithms are procedures for processing stimuli of a certain type, and thus any gain in efficiency that accrues from practice will benefit all tokens of that type.

Findings such as these have provided an increasing amount of support for memory-based processing accounts of automaticity. However, the empirical evidence for these theories has come almost exclusively from examination of fairly simple cognitive tasks (e.g., alphabet arithmetic, dot counting). Given that memory-based processing accounts have been proposed as general theories of automaticity, they clearly would profit from further testing of their key assumptions in the context of more complex cognitive tasks. Although the various mechanisms that have been proposed to account for speed-ups with practice are not mutually exclusive (i.e., more than one mechanism may contribute to speed-ups in performance of a task), theorists acknowledge that the contribution of any given mechanism to automatization may change drastically across tasks, with some mechanisms playing a large role in some tasks but a minimal role in others (e.g., Blessing & Anderson, 1996; Haider & Frensch, 1996; Logan, 1988). Indeed, researchers have acknowledged that automaticity theories "have had considerable success in addressing the fine details of learning relatively simple tasks. While encouraging, these demonstrations leave the worry that there may be problems with scaling up to the complex tasks that are more typical of human learning in the real world" (Lee & Anderson, 2001, p. 268).

Automaticity in Text Comprehension

Although the primary goal of the present research was to investigate the nature of automaticity in text comprehension, an important by-product of this research will be a test of memory-based processing accounts in a more complex task. Text comprehension provides a particularly good proving ground for memory-based processing accounts of automaticity, because it is a relatively complex cognitive task involving a system of coordinated processes that interpret many different kinds of information. Importantly, many of the units of information processed in text comprehension are encountered repeatedly in natural language (e.g., sounds, letters, words, propositions, phrases), which is a necessary condition for the memory-based processing mechanism to operate. Thus, examining the memory-based processing mechanism in text comprehension affords a test of the generality of these accounts for more complex tasks.

Of key importance here, theories of text comprehension will profit from a process-oriented conceptualization of automaticity, given that automaticity is a ubiquitous concept in the text comprehension literature. General models of text comprehension often include assumptions about the automaticity of the comprehension system (e.g., Just & Carpenter, 1980; Kintsch, 1998; Perfetti, 1988; Walczyk, 2000). Similarly, many of the specific component processes in the comprehension system have been described as involving 'automatic' processing, including lexical processing, syntactic parsing, and inferencing (e.g., Brown, Gore, & Carr, 2002; Hahne & Friederici, 1999; Kintsch, 1993; McKoon & Ratcliff, 1992; Rayner & Frazier, 1989). However, despite the ubiquity of assumptions about automaticity in this literature, memory-based processing accounts of automaticity (and other mechanism-based accounts) have not been systematically tested in text comprehension research.

This paucity of research is understandable given that the conceptualization of automaticity in the text comprehension literature has almost exclusively involved property-list accounts like those described earlier. One problem that has plagued text comprehension research is lack of agreement about what properties are necessary and sufficient to define automaticity (for further discussion and illustration of this problem, see Rawson, 2004). More important, even if consensus could be reached about the necessary and sufficient properties for defining automaticity in text comprehension, property-list accounts are inherently limited in their explanatory power, as described earlier. Given these concerns, incorporating mechanism-based accounts of automaticity into theories of text comprehension processes will significantly advance this area. Indeed, one purpose of the current work is to advocate for a movement away from property-list accounts that motivate descriptive studies to mechanism-based accounts that motivate investigation of how the underlying processes and representations involved in text comprehension change with practice. For example, the goal of the present research was not to describe whether performance is ballistic, effortless, autonomous, and so on. Rather, the present research was designed to investigate the extent to which the retrieval of prior interpretations of particular stimuli increases with practice during text comprehension.

Although minimal text comprehension research has directly investigated increases in the retrieval of prior interpretations of particular stimuli with practice, several theoretical claims and empirical findings in the extant literature are relevant to memory-based accounts. Although an exhaustive review is beyond the scope of this article, one illustrative example comes from the ongoing debate in the literature on morphological processing concerning the extent to which familiar polymorphemic words (e.g., *walked, horses, snowing*) are decomposed into their constituent morphemes (*walk* + *ed*) versus accessed as whole words from the lexicon (e.g., Baayen, Dijkstra, & Schreuder, 1997; Schreuder & Baayen, 1997; Taft, 2004). Accounts that assume a parallel race between decomposition and whole-word access are receiving increasing attention and empirical support. For example, Baayen et al. reported evidence for whole-word access of high-frequency plural nouns, and simulation modeling suggested this was due to the relative speeds of access versus decomposition. A similar debate concerns the extent to which familiar compound words (e.g., *doorbell*) are decomposed during visual recognition versus identified via whole-word recognition (e.g., Jarema, Busson, Nikolova, Tsapkini, & Libben, 1999; Libben, Gibson, Yoon, & Sandra, 2003; Pollatsek, Hyönä, & Bertram, 2000), with some evidence supporting a parallel race model (e.g., Pollatsek et al., 2000).

Importantly, however, these studies were not designed to directly test memory-based accounts of automaticity and thus did not examine shifts from algorithmic-based processing to retrieval-based processing with practice.[1] One recent study has provided a direct test of the memory-based processing account of automaticity in text comprehension. Rawson (2004) examined the pattern of reading times for target

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[1] Regarding the applicability of previous research to memory-based processing accounts of automaticity in text comprehension, we also note that most previous research involved recognition decisions to words in isolation. As Pollatsek et al. (2000) note:

> "The results from the lexical-decision task may not generalize to normal reading, because lexical-decision latencies often tap postaccess decision making that is likely to be unrelated to postaccess processing in reading comprehension. Moreover, strategic factors having to do with the stimulus environment have been shown to modulate the pattern of results in lexical decision . . . silent reading is a better paradigm for investigating how compound words are processed when people are processing for meaning." (p. 822)

sentences with syntactic structures that were either more or less difficult to interpret. The target sentences were embedded in short stories that were presented either repeatedly or only once during practice. On the first practice trial for repeated items, reading times were slower for sentences with more difficult syntax than for those with less difficult syntax. In contrast, by the last practice trial, reading times for the two sentence types were virtually identical. This finding is analogous to the minimization of digit-addend effects with practice (Logan & Klapp, 1991) and presumably reflected a shift from algorithmic processing to retrieval of sentence interpretations by the end of practice. As further evidence, reading times were significantly faster for the repeated sentences than for novel sentences with the same syntactic structure, analogous to the item-specific practice effects shown in alphabet arithmetic (Logan & Klapp, 1991). Thus, Rawson provided initial evidence for a role of memory-based processing in the automatization of syntactic processing. However, no other work has directly tested memory-based processing accounts of automaticity in text comprehension.

To further investigate automaticity in text comprehension, the present research introduces a new method for testing the generality of memory-based automatization of text comprehension processes. To foreshadow, we devised a transfer task to examine the extent to which memory-based processing contributes to the interpretation of a particular stimulus when that item is reencountered outside of the context in which it was originally presented. The role of memory-based processing in the interpretation of repeated items across different contexts must be established before any strong claims can be made about the generality of this mechanism in text comprehension. In Rawson's (2004) study, target items were always repeated in the same contexts. Thus, the initial evidence for a contribution of memory-based processing to the automatization of a comprehension process rested on an implicit and untested assumption that interpretations of repeated items stored during practice would have been available for retrieval if those items had later appeared in different contexts. However, the possibility remains that the item-specific interpretations that were encoded were contextually bound and thus would not have been available outside of their original context (for evidence consistent with this possibility, see Levy & Burns, 1990). Accordingly, the present research examined the involvement of memory-based processing in the automatization of a comprehension process when target items are presented outside of the contexts in which they were originally encountered.

To further establish the generality of memory-based processing in the automatization of text comprehension processes, we explored the contribution of memory-based processing to speed-ups in a different component process within the text comprehension system. As noted above, theorists acknowledge that any given automaticity mechanism can play a large role in some tasks but a minimal role in others. Thus, the initial evidence that memory-based processing plays a role in the automatization of syntactic processing (Rawson, 2004) does not warrant the conclusion that memory-based processing will contribute to the automatization of other text comprehension processes more generally. Examining memory-based processing in a different component text process would support stronger claims about the generality of memory-based processing in the automatization of text comprehension. Accordingly, the present research tested the memory-based processing account of automaticity in one of the many semantic processes involved during text comprehension.

Conceptual Combination as a Test Case

Specifically, the present research examined changes in performance with practice during *conceptual combination*. Conceptual combination involves combining the concepts denoted by two or more words, resulting in either the modification or elaboration of the characteristics of a base concept or the creation of a new concept altogether. Typical combinations in English involve adjective-noun combinations (e.g., *muddy ideas*) or noun-noun combinations (e.g., *poster child*).

Noun-noun combinations are well suited for present purposes. Sociocultural or technological changes in the world often create the need to express new concepts, and thus novel combinations are frequently introduced into a language (see Table 1 for real-world examples of novel noun-noun combinations; these items are for illustration and were not used in the present study). Many combinations are repeated often enough within a language to become familiar to most users of the language (e.g., *dog sled*, *computer screen*). Does the processing of noun-noun combinations change as they transition from novel to familiar (i.e., with repetition)?

Table 1
Examples of Novel Noun-Noun Combinations

Text excerpts
The stranger instructed Jack Fleming to bear right on County Road 905. "It says there's a toll," Jack said. "Yeah?" "Look, we're out of money." A soggy ten-dollar bill landed on the front seat between Jack Fleming and Webo Drake. Again the earthquake voice: "Stop when we reach the bridge." (Hiassen, *Stormy Weather,* 1995, p. 9).
The cousin had started out as a comedian many years ago (he was now over fifty), moved into psychotherapy, and now counseled only the dying. He called himself a death therapist. (Smiley, *Horse Heaven*, 2000, p. 213).
Lightning Calculators are people who can do mental arithmetic very fast in their heads without using a pencil, paper or a calculator. There are a few very rare individuals who can do this, because they have a special gift, and they are often unaware of how they do the calculations. (University of Western Ontario, Department of Physics and Astronomy, 2001).
Thereafter only when a strong wind was blowing did a faint, sickly odor coming from the east remind them that they were living under a new order and that the plague fires were taking their nightly toll. (Camus, *The Plague,* 1947/1948, p. 162).
"It must have cost a lot." "Nobel Prize money bought it. Two things that money bought: a cottage on Cape Cod and that monument." (Vonnegut, *Cat's Cradle*, 2006, p. 65).
Père Goriot made a gesture as if to clutch something upon his breast and uttered plaintive, inarticulate cries like those of an animal in pain. "Oh," Bianchon said, "he wants a little hair chain and a locket that we took off a few minutes ago when we applied the caustic. Poor man, we must give it back to him. It is on the mantelpiece." Eugène took up the chain made of braided pale blond hair that had no doubt been Mme. Goriot's. (Balzac, *Père Goriot,* 1835/1980, p. 366).

Note. Above are real-world examples of novel noun-noun combinations and the literary contexts in which they appeared. These examples are presented for illustrative purposes and were not used in the present experiments.

According to the memory-based processing account, processing of a combination will shift from algorithm-based interpretation to retrieval of prior stored interpretations with increasing encounters of that combination. In contrast, some theorists assume that algorithmic processes underlie interpretation of both novel and familiar combinations. For example, according to the *competition among relations in nominals* theory (CARIN; Gagné & Shoben, 1997), interpretation of noun-noun combinations involves selection of a thematic relation to guide an inference about how the two nouns are related (e.g., for *mountain cloud*, the relation *in* guides the inference that this combination refers to "a cloud in the mountains"). Relations compete for selection, with the ease of interpretation influenced by the relative frequencies of the various relations associated with the modifier noun (e.g., *mountain* as a modifier noun is most frequently associated with the *in* relation, as above). Although CARIN was originally proposed to account primarily for the processing of novel combinations, the same algorithmic processes have recently been proposed to underlie the interpretation of familiar combinations as well (Gagné & Spalding, 2004; Gagné, Spalding, & Gorrie, 2005; to foreshadow, we consider how the present results bear on this account in the *General Discussion*).

In contrast, the memory-based processing account assumes that the involvement of algorithmic processes will decrease substantially as combinations become familiar. As explained earlier, this is not to say that algorithmic processing necessarily drops out altogether. As Gagné and Spalding (2006) have recently suggested, both algorithmic and retrieval-based processes may be initiated when a familiar combination is encountered, although they note that "accessing the established meaning of the compound may usually be so quick that the relation selection process need not reach completion" (p. 13). In sum, the main claim of memory-based processing accounts is that retrieval will drive interpretation on an increasing number of trials as the number of stored instances increases with practice.

Although plausible, an increasing involvement of memory-based processing as combinations transition from novel to familiar is not a foregone conclusion. Interpretation of combinations may continue to be primarily based on an algorithm with some degree of item-generality (as in the CARIN model described above), and speed-ups with practice could be due to increased efficiency of these algorithmic processes.[2] Furthermore, even if interpretations of particular stimuli are stored in long-term memory, retrieval of those interpretations on subsequent encounters of the stimuli may not be fast or reliable enough to support interpretation. To revisit, instance theory assumes that upon encounter of a repeated item, the algorithm and retrieval routes to interpretation race in parallel, with stimulus interpretation based on the output of whichever process finishes first. Retrieval may fail to win if practice sufficiently improves the efficiency of the algorithm, if instances are slow to be retrieved due to forgetting across delays, and/or if instances are slow to be retrieved due to changes in the context in which stimuli are encountered (factors that will be examined in the current research). If so, memory-based processing will have a negligible influence on performance.

To test the memory-based processing account, the present research examined changes in performance with practice using novel noun-noun combinations that had more than one possible interpretation, a *dominant* meaning (the meaning most frequently generated by participants in a norming study) and a *subordinate* meaning (a plausible alternative interpretation). Combinations were embedded in short story contexts. In each story, the sentence containing the combination was followed by a target sentence with a *disambiguating region* that contained information indicating the intended meaning of the combination (see examples in Table 2). In all three experiments, stories were presented repeatedly throughout practice, with either the dominant or subordinate meaning in the disambiguating region (the *repeated dominant* and *repeated subordinate* conditions). Experiment 1 also included a condition in which stories with subordinate meanings were each presented only once during practice (the *unrepeated subordinate* condition). Experiments 2 and 3 included a transfer phase in which the combinations repeated during practice were presented in new sentence contexts in a different task. Importantly, the new sentence context either disambiguated with the same meaning from practice or with the other meaning. A self-paced moving window method was used to permit examination of reading times in critical sentence regions. Across experiments, the memory-based processing account predicts three key patterns of results. All three predictions concern reading times in the disambiguating region of the target sentences.

> *Prediction 1.* The first time to-be-repeated items are presented, all combinations are unfamiliar, and thus no prior interpretations are available to be retrieved. Thus, an algorithm must generate a meaning for the combination, most likely the dominant meaning (given that it is most often generated by participants in norming studies). If the subsequent target sentence disambiguates with the subordinate meaning, reinterpretation will be necessary. Thus, on Trial 1, reading times will be longer in subordinate disambiguating regions than in dominant disambiguating regions (i.e., a semantic garden-path effect will obtain). In contrast, by the end of practice, the correct interpretations of repeated combinations that were stored on previous trials can be retrieved. If so, retrieved interpretations will be consistent with the disambiguating information, and thus no difference in reading time is predicted for these two conditions at the end of practice. All three experiments tested this prediction.

> *Prediction 2.* By the end of practice, processing of repeated combinations is assumed to involve the retrieval of prior interpretations, which minimizes the need for reanalysis of

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[2] Note that we limit our discussion here to mechanisms that may underlie speed-ups with practice for unfamiliar items in a familiar task. We assume that although the particular noun-noun combinations used in the current study were unfamiliar to our participants, the adult readers in our study have had many years of experience processing combinations more generally. Thus, we assume that participants began the experiment already equipped with item-general algorithms for processing combinations. Accordingly, two of the mechanisms most likely to explain practice effects in the current study are increases in the efficiency of existing item-general algorithms and shifts to memory-based processing. By contrast, in some other studies of automaticity, the task itself has been unfamiliar to participants. For unfamiliar tasks, speed-ups with practice may also be due to the acquisition of the item-general algorithms for processing the type of stimuli encountered in the novel task (for discussion of how task-relevant algorithms may be acquired by applying domain-general analogy procedures to declarative examples or instructions, see Anderson & Fincham, 1994).

Table 2
Sample Novel Combinations and Corresponding Texts From Experimental Materials

Experimental texts
Dr. Collins, a renowned entomologist from UCLA, and two graduate students, Sally and Arthur, spent their summer break in the African Congo, cataloguing new species of insects. For Sally, discovering new species was difficult and tedious, and she found it unrewarding until she made an interesting find. The bee spider was the most exciting discovery of the entire trip. *It was a spider [that looked like a bee/that only ate bees].* Dr. Collins awarded her a fellowship and booted Arthur out of the program because he was a slacker.
Comprehension question: Did Dr. Collins discover a new species?
Willy was my best friend when I was a child. His family lived two houses down the street from us in a slightly dilapidated ranch with a huge wraparound porch. When I would go to fetch Willy, his grandfather was invariably on the front porch, sucking on his false teeth and scowling at the pigeons. Willy had warned me about his grandfather's firecracker temper many times. *Grandfather would really lose his temper [as quick as a firecracker/when kids played with firecrackers].* Willy and I steered clear of him excepting our various mischievous urges to incite the old gaffer to shake his fist and curse us.
Comprehension question: Was Willy's grandfather an old grump?
Marcia was starting to think that she was never going to finish her dissertation work. Even though her mentor had advised her against it, she had chosen to pursue one of the more difficult lines of research in marine biology. She was trying to identify the influence of pollution on the rate of aquatic diseases in tropical species. Her work was challenging because the particular species she had chosen to study was quickly moving toward the endangered species list, so there weren't many specimen to observe. As if the work wasn't difficult enough already, lately things had gotten even worse. The shark virus was really slowing her work down. *She certainly had not expected the virus that suddenly* [*attacked the sharks she was studying/attacked her viciously like a shark*]. She realized that she just may not finish her dissertation until next year.
Comprehension question: Had Marcia chosen a very difficult topic for her dissertation?

Note. For illustrative purposes here, novel combinations are underlined and the disambiguating sentences are italicized. In the experiment, the disambiguating sentence contained either the dominant meaning (the first phrase in the bracket) or the subordinate meaning (the second phrase in the bracket). The full set of materials is available from the first author.

subordinate items (as explained above). In contrast, interpretation of unrepeated subordinate items relies on algorithmic processing, which is most likely to generate the dominant meaning. If so, reanalysis will be needed in the subordinate disambiguating region for unrepeated items, and thus reading times will be longer in the disambiguating region for unrepeated subordinate items versus for repeated subordinate items. Experiment 1 tested this prediction.

Prediction 3. The third prediction concerns reading times in the transfer task and is arguably of greatest interest, given that it bears on the involvement of memory-based processing when target items are presented outside of the contexts in which they were originally encountered. The memory-based processing account assumes that when combinations are encountered in the transfer task, interpretations stored during practice will be retrieved, despite the fact that the combination is now presented in a new sentence context. If the retrieved interpretation is consistent with the subsequent disambiguating information, no reanalysis will be needed. However, if the retrieved interpretation is not consistent (half the items will have a different disambiguated meaning in transfer than in practice), reanalysis will be needed in the disambiguating region. Thus, for items that disambiguate with the subordinate meaning in transfer, reading times in the disambiguating region are predicted to be longer for items that had been practiced with the dominant meaning than for items practiced with the subordinate meaning. Similarly, for items that disambiguate with the dominant meaning in transfer, reading times in the disambiguating region will be longer for items that had been practiced with the subordinate meaning than for items practiced with the dominant meaning. By comparison, if memory-based processing is not involved in interpretation of the combinations during transfer, processing of combinations will revert back to the algorithm, which is most likely to generate the dominant meaning. In this case, only a main effect of the meaning in transfer would be predicted, with longer reading times for transfer items that disambiguate with the subordinate versus dominant meaning. Experiments 2 and 3 tested these predictions.

Experiment 1

Method

Materials. To develop experimental materials, we constructed 30 noun-noun combinations (see Appendix). As an indicator that the combinations would be relatively unfamiliar to most participants, we confirmed that none of the combinations appeared as bigrams in the American National Corpus (http://www.americannationalcorpus.org/frequency.html) or in the Oxford English Dictionary. We then wrote a short narrative for each of the 30 combinations (see sample texts in Table 2). In a norming study, we presented each text up to and including the sentence that contained the novel combination (e.g., in Table 2, the first text was presented up to and including ". . . the bee spider was the most exciting discovery of the entire trip"). Below each story was a meaning generation prompt including the target noun phrase (e.g., "What is a bee spider?") and a blank line. Participants were instructed that after reading a story they should write down what they thought was the most likely meaning of the target noun phrase. They were told that there were no right or wrong answers and that their answer should be something like a general definition of the target noun phrase. On average, 77% of participants generated the same meaning for each combination (the *dominant* meaning). We also selected an alternative meaning for each combination (the *subordinate* meaning) that would also be sensible in the story context. Across combinations, only 6% of participants in the norming study generated the subordinate meaning.

In the full texts used in Experiment 1, the sentence containing the combination was followed by the target sentence and then some filler material to conclude the story. In each target sentence, the *disambiguating region* was the phrase containing the information that indicated the intended meaning of the novel combination (see Table 2). Two versions of the disambiguating region were written for each target sentence, one supporting the dominant meaning and one supporting the subordinate meaning. For example, in the "bee spider" story (Table 2), the disambiguating region was "that looked like a bee" in the dominant version and "that only ate bees" in the subordinate version. The dominant and subordinate disambiguating regions for each target sentence were matched as closely as possible for number of letters ($M = 25.7$ for dominant, $M = 24.8$ for subordinate), syllables ($M = 7.9$ for dominant, $M = 8.0$ for subordinate), mean log word frequency across all words in the region (Brown, 1984, verbal language frequency, $M = 4.5$ for dominant, $M = 4.2$ for subordinate), and mean log word frequency across only content words ($M = 2.7$ for dominant, $M = 2.3$ for subordinate).

Texts were assigned to one of four conditions, counterbalanced across participants (achieved by randomly dividing texts into six sets of five texts and then using Latin square to assign sets to conditions). For each participant, 15 texts included the subordinate version of the target sentence; one set of five texts was assigned to the *repeated-subordinate* condition, and two sets of five were assigned to the *unrepeated-subordinate* condition. (Given that unrepeated texts could only be presented once during practice, more texts were assigned to the unrepeated condition than the repeated condition to permit inclusion of unrepeated items in each block of practice). Likewise, for each participant, 15 texts included the dominant version of the target sentence; one set of five was assigned to the *repeated-dominant* condition, and two sets of five were assigned to the *unrepeated-dominant* condition (although the unrepeated-subordinate condition is of greater interest for testing the memory-based processing account, including unrepeated dominant items discourages readers from assuming that all unrepeated items disambiguate with a nondominant meaning).

Procedure. As a cover task, participants were told that the experiment was examining how rereading improves memory and comprehension. They were instructed to read each text carefully and answer as many comprehension questions correctly as possible. Sample filler texts were also presented to familiarize participants with the moving window procedure used during the experiment. In the moving window procedure, each text is presented one segment at a time. Texts were segmented at natural phrase boundaries, resulting in segments of 1–9 words in length. Within the target sentences, all of the information needed to disambiguate the meaning of the combination was presented within one segment (i.e., the disambiguating region). The first segment of a text was presented in the upper left of the computer screen. When the participant pressed the spacebar, characters in the first segment were replaced with dashes and the next segment was presented to the right of the first. Each subsequent segment was presented in a similar manner until the end of the text. Participants were not permitted to move backward to reread previous segments. During presentation, the computer program monitored for cases in which the mean reading time for 10 consecutive regions was less than 200 ms. If so, the text was temporarily removed from the screen, and a warning was displayed for 4 s ("TOO FAST!! Please read each text carefully. The story will continue in a moment."). Text presentation then resumed at the same point as before the warning.

Experimental texts were presented in six blocks of trials. In the repeated-dominant and repeated-subordinate conditions, each text was presented once in each of the six blocks. In the unrepeated-dominant and unrepeated-subordinate conditions, each text was only presented in one block of trials. Specifically, two texts from each unrepeated condition were presented in Block 2, two other texts from each condition were presented in Block 3, and so on for Blocks 4, 5, and 6. Within each block of trials, texts were presented in random order (randomized anew for each participant), with the provision that at least eight other texts intervene between each presentation of a repeated text.

Upon reaching the end of a text, the computer displayed a yes/no comprehension question. For repeated texts, a different question was presented after each trial. Each question tapped understanding of nontarget material within the text (see examples in Table 2). Comprehension questions were included to support the cover task instructions and to encourage participants to read each text carefully. Although performance on the comprehension questions was not of theoretical interest, we did use low performance as a basis for excluding participants from analysis. Given that the comprehension questions were relatively easy to answer, relatively low performance was taken to indicate insufficient attention to the text material.

Participants and design. Forty-two undergraduates participated for course credit in General Psychology. Presentation condition (repeated dominant, repeated subordinate, unrepeated dominant, or unrepeated subordinate) was a within-participant manipulation. The primary dependent variable was reading time in the disambiguating region of target sentences.

Results and Discussion

Data for 1 participant who only completed the first four blocks of trials were excluded from analyses. Data for 5 other participants were excluded from analyses due to performance below 75% correct on the comprehension questions or because they received nine or more "TOO FAST" warnings. Across the remaining 36 participants, comprehension performance was relatively high ($M = 90\%$) and the number of warnings was relatively low ($M = 1.92$), suggesting reasonable attention to the task throughout practice. Analyses by subject and by item are reported as F_1 and F_2, respectively. Effect size (d) is reported with each paired comparison below.

We computed mean reading time in the disambiguating region within each block of trials for each condition (Figure 1). Reading times that were 100 ms or less were excluded from analysis. Reading times greater than 9,000 ms were also excluded, as they most likely reflected lapses of attention. Less than 1% of reading times were dropped based on these criteria.

For the repeated items, a 2 (meaning) × 6 (block) repeated measures analysis of variance (ANOVA) revealed significant main effects of meaning and block and a significant interaction, meaning: $F_1(1, 35) = 4.60$, $MSE = 111{,}498$, $p = .039$, $F_2(1, 29) = 3.37$, $MSE = 137{,}140$, $p = .077$; block: $F_1(5, 175) = 197.09$, $MSE = 112{,}015$, $p < .001$, $F_2(5, 145) = 250.90$, $MSE = 303{,}815$, $p < .001$; interaction: $F_1(5, 175) = 6.08$, $MSE = 40{,}908$, $p < .001$, $F_2(5, 145) = 8.71$, $MSE = 88{,}534$, $p = .006$. Reading times were significantly faster during the sixth block of practice than during the first block of practice in the repeated-dominant condition, $t_1(35) = 13.83$, $p < .001$, $d = .22$; $t_2(29) = 12.06$, $p < .001$, and in the repeated subordinate-condition, $t_1(35) = 17.05$, $p < .001$, $d = .20$; $t_2(29) = 15.28$, $p < .001$. Thus, the signature pattern of automatization was evident in both conditions. More important, key paired comparisons provided evidence that these speed-ups with practice were due to increasing involvement of memory-

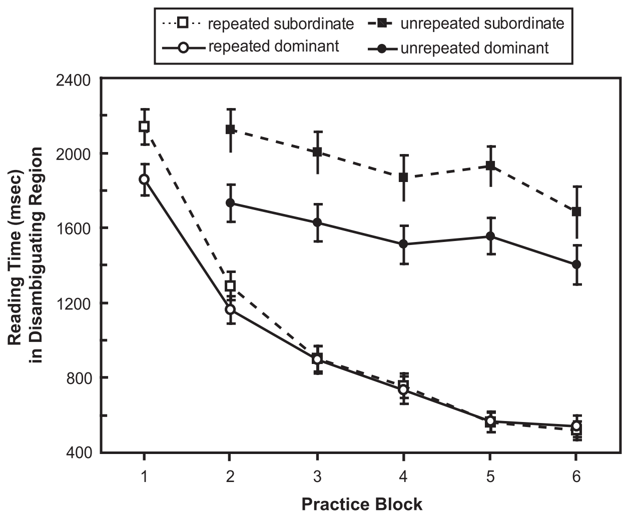

Figure 1. Mean reading time in the disambiguating region of target sentences in Experiment 1 as a function of the meaning of the conceptual combination, number of presentations, and practice block. Error bars represent standard error of the mean.

based processing in the repeated conditions. Reading times were significantly slower in the repeated-subordinate condition than in the repeated-dominant condition during the first and second blocks of practice, first: $t_1(35) = 3.38$, $p < .001$, $d = .15$, $t_2(29) = 3.13$, $p = .002$; second: $t_1(35) = 2.29$, $p = .014$, $d = .13$, $t_2(29) = 2.10$, $p = .022$. In contrast, reading times in these two conditions did not significantly differ during any of the other practice blocks (all t_1s < 0.72; all t_2s < 0.39). Thus, Prediction 1 (that reading times would differ at the beginning but not at the end of practice) was supported.

To revisit, the memory-based processing account assumes that, on the first trial, the to-be-repeated combinations are still unfamiliar, and thus an algorithm must generate an interpretation. The algorithm is most likely to generate the dominant meaning for all combinations. If so, in the subordinate condition, reanalysis is subsequently needed in the disambiguating region to correct the initial misinterpretation, and thus reading time is elevated. However, when the repeated combinations are encountered on later trials, the correct interpretations encoded on previous trials are retrieved. If so, reanalysis is no longer needed in the subordinate conditions, and reading times in the two conditions no longer differ, as observed.

Regarding the convergence of reading times on later trials, an alternative possibility is that interpretation at the point of the combination is still based on algorithm (rather than retrieval of prior interpretations), but processing of the subsequent disambiguating information is delayed. In other words, reanalysis may still be needed in the subordinate condition, but that reanalysis may be postponed on later trials. If so, the elevation of reading times in the repeated-subordinate condition would no longer appear in the disambiguating region but would instead appear in the region immediately after. To evaluate this possibility, we examined reading times in the moving window segment that was presented immediately after the disambiguating region, referred to as the *spillover region* (e.g., in the "firecracker temper" text in Table 2, the spillover region contained the noun phrase "Willy and I" presented immediately after the disambiguating region). Inconsistent with this alternative interpretation, reading times in the spillover region for the two conditions (see Table 3) did not significantly differ on any trial (all t_1s and t_2s < 0.57 for Blocks 1–4 and < 1.44 for Blocks 5–6, with the trend in the opposite direction than expected by this alternative).

Further evidence for the involvement of memory-based processing comes from comparison of reading times in the disambiguating region in the repeated and unrepeated subordinate conditions. In Blocks 2–6, reading times were significantly faster for repeated subordinate items than for unrepeated subordinate items (all t_1s and t_2s > 7.34, *p*s $< .001$, *d*s $> .16$). Thus, Prediction 2 was supported. The sizeable difference in response times for repeated

Table 3
Mean Reading Times (in ms) in Spillover Region for Repeated Items in Experiments 1–3

Experiment/ condition	Statistic	Practice block								
		1	2	3	4	5	6	7	8	9
Experiment 1										
Subordinate	*M*	1,297	957	702	622	492	458			
	SE	49	57	41	45	37	31			
Dominant	*M*	1,278	964	716	619	527	487			
	SE	71	49	42	49	46	35			
Experiment 2										
Subordinate	*M*	1,296	956	740	598	517	451			
	SE	56	47	36	30	30	24			
Dominant	*M*	1,223	919	711	624	498	440			
	SE	53	42	36	38	25	20			
Experiment 3										
Subordinate	*M*	1,351	1,029	792	1,004	769	642	851	646	530
	SE	48	42	40	43	44	35	43	40	31
Dominant	*M*	1,281	913	767	971	779	616	821	614	528
	SE	45	35	40	42	43	31	43	34	28

Note. *SE* = standard error of the mean. The spillover region is the segment of text that was presented immediately after the disambiguating region of the target sentence in each text.

versus unrepeated items weighs strongly against the possibility that speed-ups observed in the repeated conditions were solely due to increased efficiency of item-general algorithms and the possibility that speed-ups were solely due to general task familiarity (e.g., remembering which key to use). The modest decrease in reading times in the unrepeated conditions provides some estimate of the potential effect of these factors; clearly, the speed-up in the repeated condition involves some other factor above and beyond item-general and task-general factors.

Specifically, according to the memory-based processing account, when repeated subordinate items are encountered in later blocks of practice, the correct interpretations encoded on previous trials are retrieved. As a result, reanalysis in the disambiguating region is avoided for repeated items. In contrast, unrepeated items continued to be processed via the algorithm, which results in the need for reanalysis in the disambiguating region for unrepeated subordinate items. Evidence for this assumption comes from the finding that reading times for the unrepeated subordinate and unrepeated dominant conditions continued to differ throughout practice (all t_1s > 1.96, ps $< .03$, ds $> .14$; all t_2s > 1.08), in contrast to the convergence of reading times for the two repeated conditions. This differential pattern of convergence versus divergence in the repeated versus unrepeated conditions provides further evidence for a differential basis of processing by the end of practice (presumably, memory-based processing in the repeated conditions versus algorithmic processing in the unrepeated conditions).

Experiment 2

Experiment 1 provided initial evidence for the involvement of memory-based processing in the automatization of conceptual combination during text comprehension. Experiment 2 provided an important extension by investigating the extent to which memory-based processing contributes to conceptual combination when items are repeated in different contexts, which must be established before any strong theoretical claims can be made about the generality of this mechanism in text comprehension processes.

Method

Materials. Materials for the *practice* phase included 24 of the experimental texts used in Experiment 1. For the *transfer* phase, we wrote 24 transfer sentences, each containing one of the combinations that had been presented during the practice phase. Importantly, the sentence in which the combination appeared during transfer was different from the sentence in the story in which it had been repeated during practice. For example, during practice, "firecracker temper" appeared in the sentence, "Willy had warned me about his grandfather's firecracker temper many times" (see Table 2). However, during transfer, "firecracker temper" appeared in a sentence that began, "At family reunions, Bobby kept an eye out for his uncle's firecracker temper because he was prone to get angry. . ." (see Table 4). We then conducted a norming study for the transfer sentences. For each combination, participants were presented with the transfer sentence up to but not including the disambiguating information and were asked to generate the most likely meaning of the combination. Between 14–25 undergraduates who participated for course credit responded to each item. Responses were consistent with those from the original norming study for the practice texts, with dominant meanings generated by participants 76% of the time across items and subordinate meanings generated 4% of the time.

Table 4
Sample Target and Filler Sentences From Transfer Phase of Experiments 2–3

Target sentences:
At family reunions, Bobby kept an eye out for his uncle's firecracker temper because he was prone to get angry *as quick as a firecracker/ when kids play with firecrackers*. [sensible]
Billy had repeatedly asked his folks for a cheetah bike for Christmas, because he knew the *really fast/tan and spotted* bike would make him the coolest kid in the clouds. [nonsensical]
Filler sentences:
At the party, Wayne and his wife met many of their new neighbors, had a tour of the host's home, and left the party at about ten o'clock. [sensible]
When his name was announced at the men's sports banquet, Rick got up from the table where he and his teammates had been swimming. [nonsensical]

Note. For illustrative purposes here, the combinations are underlined and the disambiguating phrases are italicized. In the experiment, the target sentence contained either the dominant meaning (the first italicized phrase) or the subordinate meaning (the second italicized phrase). Examples of sensible and nonsensical sentences are included. The full set of sentences is available from the first author.

Procedure. Participants were given task instructions similar to those in Experiment 1. During the *practice phase* of the experiment, the repeated-dominant condition and the repeated-subordinate condition were the same as in Experiment 1, except that 12 experimental texts were assigned to each condition for each participant. The unrepeated conditions used in Experiment 1 were not included, to increase the number of texts in the repeated conditions (more repeated texts were necessary to permit the manipulation of transfer meaning, described below).

As in Experiment 1, each of the texts in the two repeated conditions was presented once in each of six blocks of trials. The texts within each block were presented in random order, with the provision that at least 12 other texts intervened between each presentation of a repeated text. All texts were presented via moving window as in Experiment 1. A different yes/no comprehension question was presented after each presentation of a text.

After the practice phase was completed, the *transfer task* was administered. Participants were given cover task instructions explaining that the next task measured basic reading comprehension ability. They were instructed that on each trial, they would read a sentence one phrase at a time at their own pace, after which they would be asked to judge whether the sentence was sensible or nonsensical. They were advised to read each sentence carefully so that they could make as many correct judgments as possible. The sensibility judgment task was used to reduce the nominal similarity of the practice and transfer tasks. Performance on the sensibility judgments was therefore not of theoretical interest and was used only as an indicator of insufficient attention during the transfer task.

Participants were then presented with a list of 72 sentences, one at a time via moving window. The sentence list included the 24 transfer sentences and 48 filler sentences. Importantly, in each transfer sentence, the combination was followed by disambiguating information that was either consistent or inconsistent with the meaning that had been presented during practice. That is, half of the combinations that were repeatedly disambiguated with their dominant meaning during practice were disambiguated with their dominant meaning in the target sentences during transfer, whereas the other half were disambiguated with their subordinate meaning during transfer. Likewise, half of the combinations that were disambiguated with their subordinate meaning during practice were disambiguated with their subordinate meaning during transfer and the other half were disambiguated with their dominant meaning. Assignment of items to the four conditions (dominant versus subordinate meaning during practice and dominant versus subordinate meaning during transfer) was counterbalanced across participants (we randomly divided items into sets of six and then used Latin square to assign sets to conditions).

After reading a sentence, participants clicked on one of two buttons on the computer screen to indicate whether the sentence was sensible or not. If a participant made an incorrect judgment, the computer briefly displayed the word "ERROR" on the screen. Half of the transfer sentences in each condition and half of the filler sentences were sensible, and the remaining items were nonsensical (see examples in Table 4). All nonsensical sentences were created by replacing the final word in the sentence with a word that was semantically inappropriate in that context. (The sentence-final word occurred after the disambiguating region of target sentences, and thus reading times in the disambiguating region could not be influenced by the sensibility of the sentence.)

Participants and design. Sixty-one undergraduates participated to satisfy a course requirement in General Psychology. Practice meaning (dominant or subordinate) and transfer meaning (dominant or subordinate) were within-participant manipulations.

Results and Discussion

Data for 8 participants were excluded from analyses due to performance below 75% on the comprehension questions during the practice phase, because they received nine or more "TOO FAST" warnings during practice, and/or because performance was below 75% on the sensibility judgments during the transfer task. Across the remaining 53 participants, comprehension performance during practice was relatively high (M = 93%), the number of warnings was relatively low (M = 1.89), and performance on the sensibility judgment task was relatively high (M = 91% across sensible and nonsensical items); taken together, these results suggest reasonable attention throughout the experiment.

Although results of the transfer task are of greatest interest, we first consider patterns of reading times during the practice phase that replicate the basic findings of Experiment 1.

Reading times in disambiguating region during practice phase. We computed the mean reading time in the disambiguating region within each block of trials for each condition (Figure 2). Reading times that were less than 100 ms or greater than 9,000 ms were excluded from analyses (< 1% of trials).

A 2 (meaning) × 6 (block) repeated measures ANOVA revealed significant main effects of meaning and block and a significant interaction, meaning: $F_1(1, 52) = 71.21$, $MSE = 32{,}583$, $p < .001$, $F_2(1, 23) = 12.68$, $MSE = 84{,}487$, $p = .002$; block: $F_1(5, 260) = 194.62$, $MSE = 189{,}208$, $p < .001$, $F_2(5, 115) = 217.74$, $MSE = 74{,}969$, $p < .001$; interaction: $F_1(5, 260) = 31.60$, $MSE = 27{,}374$, $p < .001$; $F_2(5, 115) = 10.42$, $MSE = 31{,}347$, $p < .001$. Reading times were significantly faster during the sixth block of trials than during the first block of trials, in both the dominant and subordinate repeated conditions, dominant: $t_1(52) = 16.65$, $p < .001$, $d = .19$, $t_2(23) = 13.21$, $p < .001$; subordinate: $t_1(52) = 17.95$, $p < .001$, $d = .20$, $t_2(23) = 14.94$, $p < .001$, and thus the signature pattern of automatization was again evident in both conditions. As in Experiment 1, paired comparisons provided evidence that these speed-ups with practice were due to increasing involvement of memory-based processing. Reading times were greater in the subordinate condition than in the dominant condition during the first three blocks of practice, first: $t_1(52) = 10.31$, $p < .001$, $d = .06$, $t_2(23) = 4.27$, $p < .001$; second: $t_1(52) = 5.40$, $p < .001$, $d = .07$, $t_2(23) = 2.83$, $p = .005$; third: $t_1(52) = 2.36$, $p = .011$, $d = .09$, $t_2(23) = 1.71$, $p = .050$, whereas reading times in the two conditions did not significantly differ during the last three blocks of practice (all t_1s < 0.51, all t_2s < 0.60). This convergence presumably reflected a shift away from algorithmic processing to greater reliance on retrieval of prior correct interpretations in both conditions during later blocks of practice. Thus, Prediction 1 was again supported.

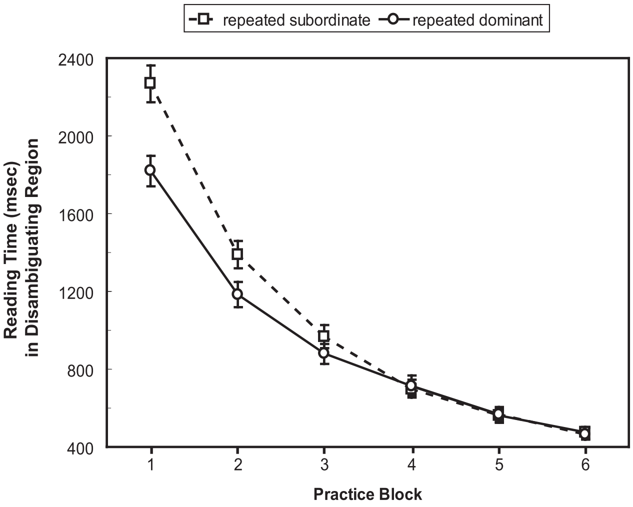

Figure 2. Mean reading time in the disambiguating region of target sentences in Experiment 2 as a function of the meaning of the conceptual combination and practice block. Error bars represent standard error of the mean.

Concerning the alternative interpretation that convergence of reading times in the two conditions reflected the postponing of reanalysis in the subordinate condition on later trials, we again examined reading times in the spillover region (see Table 3). Reading times were significantly longer in the repeated-subordinate condition than in the repeated-dominant condition in Block 1, $t_1(52) = 2.16$, $p = .018$, $d = .09$; $t_2(23) = 2.23$, $p = .018$, but did not significantly differ for the two conditions on any subsequent trial (ts < 1.46).

Reading times in disambiguating region during transfer phase. Of greatest interest, mean reading time in the disambiguating region of the transfer sentences in each of the four conditions is shown in Figure 3. Reading times that were less than 100 ms or greater than 9,000 ms were excluded from analyses (< 1% of trials).

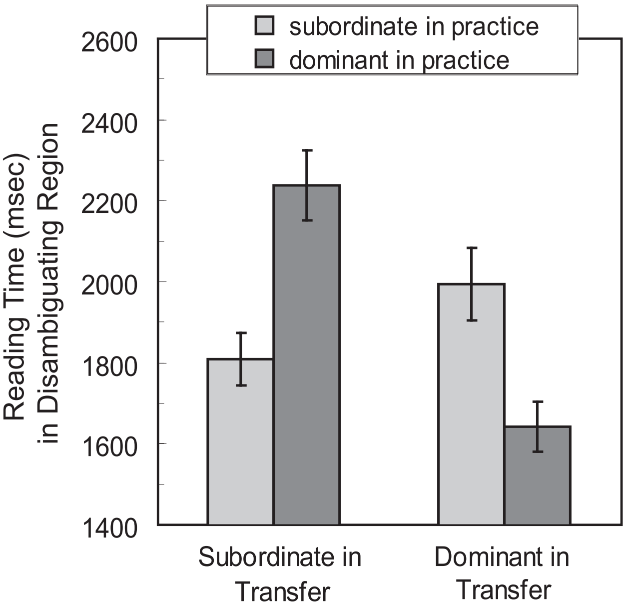

Figure 3. Mean reading time in the disambiguating region of transfer sentences in Experiment 2 as a function of the meaning of the conceptual combination during practice and during transfer. Error bars represent standard error of the mean.

A 2 (meaning in practice) × 2 (meaning in transfer) repeated measures analysis of variance (ANOVA) revealed a significant main effect of meaning in transfer, $F_1(1, 52) = 11.80$, $MSE = 189{,}371$, $p = .001$; $F_2(1, 23) = 3.27$, $MSE = 242{,}946$, $p = .084$, and a significant interaction, $F_1(1, 52) = 60.31$, $MSE = 134{,}858$, $p < .001$; $F_2(1, 23) = 35.04$, $MSE = 98{,}189$, $p < .001$. The main effect of meaning in practice was not significant (F_1 and $F_2 < 1$). Consistent with Prediction 3, paired comparisons showed that reading times on the subordinate meaning during transfer were significantly longer when that item had been practiced with the dominant meaning than when it had been practiced with the subordinate meaning, $t_1(52) = 5.61$, $p < .001$, $d = .14$; $t_2(23) = 4.03$, $p < .001$. According to the memory-based processing account, upon encounter of a combination in the transfer sentence, participants retrieved interpretations of that combination that were encoded during practice. When dominant interpretations were retrieved but the subsequent disambiguating region contained the subordinate meaning, reanalysis was required. In contrast, when subordinate interpretations were retrieved, they were consistent with the disambiguating information and no reanalysis was needed. Thus, the memory-based processing account provides a straightforward explanation for these results. The pattern is more difficult to explain if one assumes that interpretation of the combinations during transfer was based on algorithmic processing. If interpretation of the combinations reverted back to the algorithmic process in transfer (due to forgetting and/or to reduced access to the stored interpretations because of the context shift), the dominant meaning of the combinations would have been generated in both conditions regardless of the meaning during practice. Thus, reanalysis would have been required in both conditions and reading times would not have differed.

Also consistent with Prediction 3, reading times on the dominant meaning during transfer were significantly longer when that item had been practiced with the subordinate meaning than when it had been practiced with the dominant meaning, $t_1(52) = 4.90$, $p < .001$, $d = .12$; $t_2(23) = 4.09$, $p < .001$. Again, the memory-based processing account provides a straightforward interpretation of this pattern. For combinations that were practiced with their subordinate meaning, those subordinate interpretations were retrieved when the combination was encountered in a transfer sentence. When the subsequent disambiguating information supported the dominant meaning, reanalysis was needed and reading times increased accordingly, relative to transfer sentences with combinations that had been practiced with the dominant meaning. This pattern is also difficult to explain if one assumes that interpretation of the combinations during transfer was based on algorithmic processing. If so, the dominant interpretation would have been generated at the point of the combination in both conditions, the subsequent disambiguating information would be consistent with that interpretation in both conditions, and reading times would not have differed.

One additional comparison is relevant for ruling out the possibility that interpretation of the repeated combinations reverted back to algorithmic processing during transfer. For items that were practiced with the subordinate meaning, reading times were longer when the dominant meaning was presented in transfer than when the subordinate meaning was presented (the subordinate-to-dominant and subordinate-to-subordinate conditions, respectively), $t_1(52) = 2.36$, $p = .022$, $d = .13$; $t_2(23) = 1.54$, $p = .069$. Thus, a reverse garden-path effect obtained, with longer reading times for a dominant meaning than for a subordinate meaning. If interpretation of the combinations during transfer had reverted back to algorithmic processing, the algorithm would have generated the dominant meaning of the combinations. If so, reading times should have been *faster* when the disambiguating region contained the dominant meaning than when it contained the subordinate meaning. According to the memory-based processing account, reading times were longer for the dominant condition because the disambiguating meaning was inconsistent with the retrieved meaning of the combination.

Experiment 3

Overall, the results of Experiments 1 and 2 support the claim of the memory-based processing account that, with increasing practice, readers process repeated combinations primarily via retrieval of interpretations stored on previous encounters of those items. Importantly, Experiment 2 established that retrieval of prior interpretations of a combination is not dependent on repetition of the original context in which the combination was encountered. However, given that the practice phase and the transfer task were administered within one session, a potential concern is that these effects reflect a more temporary maintenance of activation rather than stable representations of prior interpretations in long-term memory that could be retrieved to support processing after a more substantial delay. To permit examination of memory-based processing across longer time intervals, Experiment 3 involved the same practice and transfer phases as Experiment 2 but distributed across days.

Method

Materials and procedure. Materials for the practice phase and the transfer task were the same as in Experiment 2. Assignment of texts to conditions and procedure was the same as in Experiment 2 with the following exceptions: The practice phase of the experiment was administered during three different sessions, with 2 days between Session 1 and Session 2 and 5 days between Session 2 and Session 3. Each session included three blocks of practice trials. The transfer task was administered in a fourth session that took place 2 days after Session 3. Participants were first given cover task instructions explaining that they would complete a series of tasks measuring basic reading comprehension ability. To make the cover story more convincing, the first task administered was a vocabulary test with 38 multiple-choice questions. The transfer task was then administered.

Participants and design. Sixty-seven undergraduates participated to satisfy a course requirement in General Psychology. Practice meaning (dominant or subordinate) and transfer meaning (dominant or subordinate) were within-participant manipulations.

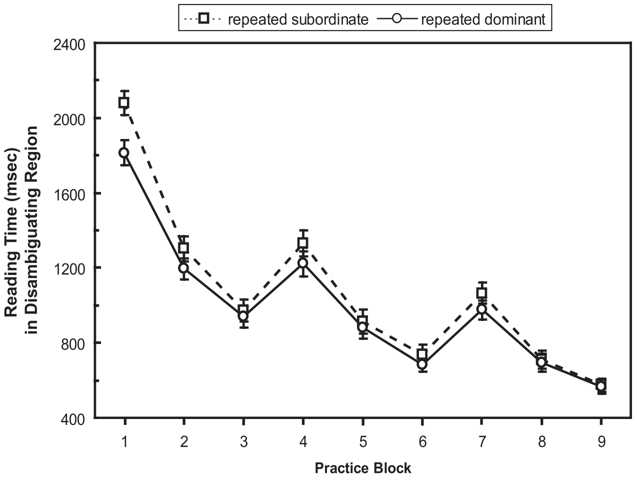

Figure 4. Mean reading time in the disambiguating region of target sentences in Experiment 3 as a function of the meaning of the conceptual combination and practice block. Error bars represent standard error of the mean.

Results and Discussion

Data for 8 participants were excluded from analyses due to performance below 75% on the comprehension questions during the practice phase, because they received nine or more "TOO FAST" warnings during one or more practice sessions, and/or because performance was below 75% on the sensibility judgments during the transfer task. Across the remaining 59 participants, comprehension performance during the three practice sessions was relatively high (M = 88–92%), the number of warnings was relatively low (M = 0.90–1.78), and performance on the sensibility judgment task was relatively high (M = 89%, across sensible and nonsensical items); taken together, these results suggest reasonable attention throughout the experiment. Four participants completed the three practice sessions but did not return for the fourth session and thus did not contribute data to analyses of transfer task performance. Session 3 data for 1 participant were lost due to experimenter error.

Reading times in disambiguating region during practice phase. We computed the mean reading time in the disambiguating region within each block of trials (Figure 4). Reading times less than 100 ms or greater than 9,000 ms were excluded from analysis (< 1% of trials).

A 2 (meaning) × 9 (block) repeated measures ANOVA revealed significant main effects of meaning and block and a significant interaction, meaning: $F_1(1, 57) = 22.03$, $MSE = 74{,}541$, $p < .001$, $F_2(1, 23) = 8.53$, $MSE = 123{,}788$, $p = .008$; block: $F_1(8, 456) = 182.58$, $MSE = 108{,}002$, $p < .001$, $F_2(8, 184) = 161.35$, $MSE = 57{,}421$, $p < .001$; interaction: $F_1(8, 456) = 7.67$, $MSE = 27{,}542$, $p < .001$, $F_2(5, 115) = 5.18$, $MSE = 31{,}093$, $p < .001$. Reading times in the disambiguating region were significantly faster during the ninth block of trials than during the first block of trials in both the dominant and subordinate conditions, dominant: $t_1(57) = 20.96$, $p < .001$, $d = .15$, $t_2(23) = 11.48$, $p < .001$; subordinate: $t_1(57) = 25.30$, $p < .001$, $d = .14$, $t_2(23) = 14.77$, $p < .001$. Paired comparisons provided evidence that these speed-ups with practice were due to increasing involvement of memory-based processing (statistics are reported in Table 5 for ease of exposition). Prediction 1 was again supported: Reading times were greater in the subordinate versus dominant condition in Block 1 but were no longer significantly different by the end of practice. Some divergence of reading times in the two conditions was observed at the beginning of Session 2 (Block 4) and Session 3 (Block 7), as well as an elevation in reading times in both conditions in these blocks, which presumably reflects some forgetting over the delay between sessions. Nonetheless, reading times were significantly faster in Block 4 than in Block 1 and significantly faster in Block 7 than in Block 4 in both conditions (all t_1s > 4.12, ps < .001, ds > .09; all t_2s > 5.14, ps < .001), showing that much of the information stored on the earlier trials was still retrievable despite the intervening days. Thus, memory-based processing was involved in interpretation even after a delay.

In the spillover region of the target sentences (see Table 3), reading times were significantly longer in the subordinate versus dominant condition in Blocks 1, 2, and 8, $t_1(58) = 1.87$, $p = .034$, $d = .10$, $t_2(23) = 1.70$, $p = .049$; $t_1(58) = 4.43$, $p < .001$, $d = .09$, $t_2(23) = 3.83$, $p < .001$; and $t_1(57) = 1.81$, $p = .038$, $d = .06$, $t_2(23) = 1.36$, respectively. Reading times in the spillover region did not significantly differ in Block 9 (t_1 and $t_2 < 0.11$), suggesting that convergence of reading times in the disambiguating region did not reflect the postponing of reanalysis.

Reading times in disambiguating region during transfer phase. Mean reading time in the disambiguating region of the transfer sentences in each of the four conditions is presented in Figure 5. Reading times that were less than 100 ms or greater than 9,000 ms were excluded from analysis (< 1% of trials).

A 2 (meaning in practice) × 2 (meaning in transfer) repeated measures ANOVA revealed a main effect of meaning in transfer, $F_1(1, 54) = 19.48$, $MSE = 135{,}577$, $p < .001$; $F_2(1, 23) = 1.39$, $MSE = 272{,}194$, $p = .250$, a main effect of meaning in practice, $F_1(1, 54) = 5.09$, $MSE = 122{,}754$, $p = .014$; $F_2 < 1$, and a significant interaction, $F_1(1, 54) = 44.53$, $MSE = 164{,}707$, $p < .001$; $F_2(1, 23) = 29.46$, $MSE = 88{,}589$, $p < .001$. Consistent with Prediction 3, paired comparisons showed that reading times on the

Table 5
Paired Comparisons of Reading Times in Repeated Subordinate and Repeated Dominant Conditions for Each Block of Practice in Experiment 3

		By subject				By item		
Session	Block	*df*	*t*	*p*	*d*	*df*	*t*	*p*
1	1	58	5.37	.001	.10	23	3.52	.001
	2	58	2.78	.004	.08	23	2.29	.016
	3	58	1.35	.092	.06	23	1.38	.091
2	4	58	3.10	.002	.07	23	2.13	.022
	5	58	1.07	*ns*	.06	23	0.67	*ns*
	6	58	1.79	.039	.07	23	0.61	*ns*
3	7	57	2.28	.013	.09	23	1.54	.069
	8	57	0.50	*ns*	.07	23	0.09	*ns*
	9	57	0.47	*ns*	.07	23	0.61	*ns*

subordinate meaning during transfer were significantly longer when that item had been practiced with the dominant meaning than when it had been practiced with the subordinate meaning, $t_1(54) = 6.10$, $p < .001$, $d = .11$; $t_2(23) = 3.42$, $p = .001$. Similarly, reading times on the dominant meaning during transfer were significantly longer when that item had been practiced with the subordinate meaning than when it had been practiced with the dominant meaning, $t_1(54) = 3.86$, $p < .001$, $d = .10$; $t_2(23) = 3.60$, $p = .001$. The memory-based processing account assumes that, in the transfer task, participants are retrieving the interpretations of the combinations that were encoded during practice. When the retrieved meaning is inconsistent with the subsequent disambiguating region, reanalysis is required and reading times increase as a result. In contrast, if interpretation of the combinations had reverted back to the algorithm during transfer (because of slowed retrieval due either to the change in context or to forgetting across the delay between practice and transfer), only a main effect of transfer meaning would have been expected, with longer reading times in the subordinate condition than in the dominant condition regardless of the meaning taken by those combinations during practice.

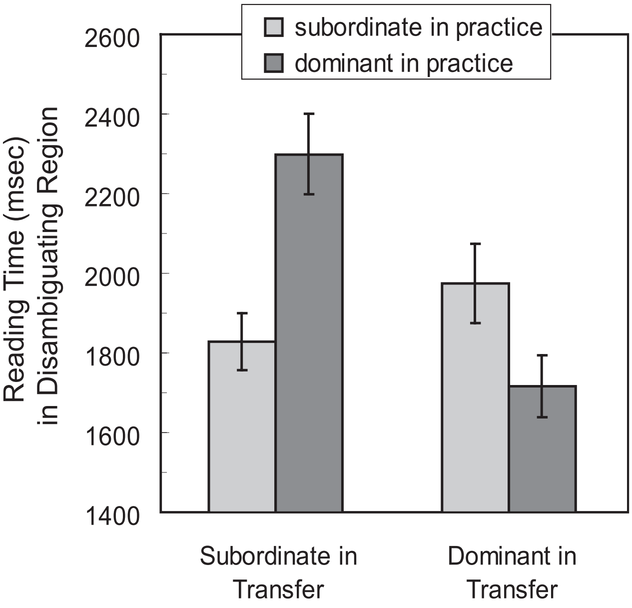

Figure 5. Mean reading time in the disambiguating region of transfer sentences in Experiment 3 as a function of the meaning of the conceptual combination during practice and during transfer. Error bars represent standard error of the mean.

Also favoring the memory-based processing account, for items that were practiced with the subordinate meaning, reading times were longer when the dominant meaning was presented in transfer than when the subordinate meaning was presented, $t_1(54) = 2.11$, $p = .020$, $d = .10$; $t_2(23) = 1.88$, $p = .037$. This reverse garden-path effect is most easily explained by the memory-based processing account, which assumes that reading times are longer in the subordinate-to-dominant condition than in the subordinate-to-subordinate condition because the disambiguating meaning is inconsistent with the retrieved meaning of the combination in the former case, and thus reanalysis is required.

In sum, Experiment 3 provides evidence that interpretations generated during practice are stored in long-term memory and are available for retrieval when those combinations are encountered after a delay and even when presented in a new context.

General Discussion

Three experiments supported the predictions of the memory-based processing account of automaticity in text comprehension. Consistent with Prediction 1, reading times were significantly longer in subordinate disambiguating regions than in dominant disambiguating regions at the beginning of practice but then converged by the end of practice in all three experiments. Presumably, differences in algorithmic demands produced the elevated reading times in the subordinate condition at the beginning of practice, whereas an increasing reliance on retrieval in both conditions produced the convergence of reading times by the end of practice. Consistent with Prediction 2, reading times in the disambiguating region were faster for repeated items than for novel items at the end of practice in Experiment 1. These item-specific practice effects presumably reflect a continued reliance on algorithmic processes for novel items versus primary reliance on retrieval of prior interpretations for repeated items. Consistent with Prediction 3, arguably the most important of the three, reading times in the disambiguating region of transfer sentences were slower when an item had been repeated with a different meaning versus the same meaning during practice, in Experiments 2 and 3. These item-specific effects in transfer are assumed to reflect the need for reanalysis when the information in the disambiguating region during transfer was inconsistent with the interpretation of the combination from practice that had been retrieved.

Implications for Theories of Automaticity

In sum, several different findings converge to support the memory-based processing account. How do other theories of automaticity fare with respect to the current results? Although Logan (1988) has explained how the assumptions of instance theory (and by extension, memory-based processing accounts more generally) are similar to and different from the assumptions of several earlier theories, we briefly consider contemporary accounts in light of the current findings. To revisit, the information reduction hypothesis (Haider & Frensch, 1996, 1999) assumes that with practice, individuals learn to ignore aspects of stimuli of a certain type that are redundant. If so, the benefit of reducing the amount of information processed should be item-general. Given the item specificity of the effects observed in practice and transfer, information reduction thus is not a viable explanation for the current findings. Similarly, any mechanism proposed to improve the efficiency of algorithms that process stimuli of a given type would produce item-general effects, such as tuning of the subsymbolic parameters in ACT-R (Anderson & Lebiere, 1998) that regulate the speed with which productions in the algorithm fire.

Of course, tuning of subsymbolic parameters is not the only learning mechanism in ACT-R that may produce speed-ups with practice. Another form of learning in ACT-R is *production compilation* (proceduralization and learning-by-analogy in older versions of the ACT theory; see also the schema acquisition account of Sweller, Mawer, & Ward, 1983). Production compilation involves the creation of new productions and is thought to take place primarily in unfamiliar situations for which no algorithmic procedure currently exists. For example, in ACT-R 4.0 (Anderson & Lebiere, 1998), compilation occurs when an individual sets a goal to learn from a specific example and/or set of instructions for a new kind of problem or task. In brief, the compilation process identifies specific values that repeat in the example or instructions and replaces them with variables that will also accept other possible slot values to create a new production that can process other token stimuli of the same type as in the example or instructions. At this stage of skill acquisition, learning involves a shift away from the use of specific declarative facts to development of more item-general procedures.

However, production compilation is unlikely to explain the current pattern of results, not only because of the item-specific nature of the effects observed here but also because adult readers have had many years of experience interpreting conceptual combinations and thus likely were already equipped with a repertoire of item-general productions that could be applied to the novel conceptual combinations presented here (see Footnote 2). In contrast, the learning mechanisms in ACT-R most likely to account for the current results include the storage of the specific solutions generated to satisfy processing goals in the form of chunks in declarative memory and the tuning of subsymbolic parameters that influence the likelihood and speed with which these declarative chunks can be retrieved on subsequent encounters of relevant stimuli. Indeed, these learning mechanisms are consistent with the memory-based processing account, and ACT-R models have successfully simulated shifts from item-general procedures to retrieval of specific solutions (e.g., in alphabet arithmetic; Anderson & Lebiere, 1998).

Of course, other interpretations are possible for some of the specific findings reported here. For example, one might argue that the advantage in reading times for repeated versus novel items during practice need not reflect retrieval of prior interpretations but rather repetition priming that facilitated processing at the word level (e.g., faster perceptual, orthographic, or phonological processing). However, previous research suggests that this possibility is unlikely, given that repetition priming effects are typically small or nonexistent when word primes are presented in text (Levy & Kirsner, 1989; Oliphant, 1983; Rawson, 2007), in contrast to the sizeable difference observed here. More generally, invoking mechanisms such as greater priming or increased familiarity of the meanings that were repeated begs the question of what exactly underlies familiarity or priming. Given that memory-based processing theorists assume that retrieval of previously stored interpretations underlies both repetition priming and automaticity (Gupta & Cohen, 2002; Logan, 1990), this argument does not pose interpretive difficulty for present purposes.

Although other alternative interpretations may be forwarded to explain particular findings here, they are unlikely to provide a comprehensive account that explains the overall pattern of results. Thus, we conclude in favor of the memory-based processing account because it provides a plausible and relatively parsimonious account of the entire pattern of results reported here. We again emphasize that we are not claiming memory-based processing to be the only mechanism of automatization in text comprehension processes, but we do believe it to be a significant contributor. Although the other mechanisms considered above are unlikely to explain the specific results reported here, they may play a significant role in the automatization of other processes involved in text comprehension.

The present work provides evidence that memory-based processing accounts of automaticity can be successfully applied to more complex cognitive tasks than the relatively simple tasks with which they have traditionally been tested. The current results also suggest that some modification of the memory-based processing accounts would improve their explanatory power. For example, reconsider the results shown in Figure 4. Reading times in both conditions increased from Block 3 to Block 4 and from Block 6 to Block 7. This pattern is sensibly interpreted as reflecting some forgetting, given that some days intervened between each of these blocks of practice. Further evidence for forgetting comes from the small but significant divergence of reading times in the repeated subordinate and dominant conditions in Blocks 4 and 7. To revisit, instance theory assumes that the algorithm and retrieval race and that stimulus interpretation is based on the output of whichever process finishes first. Slower retrieval due to forgetting across a delay increases the chance that the algorithm finishes first; if so, it most likely produces the dominant meaning, which then requires subsequent reanalysis in the subordinate condition.

On one hand, none of the memory-based processing accounts considered here explicitly include a forgetting assumption. Indeed, almost all of the recent theoretical work on automaticity is silent on the issue of forgetting (for relevant discussion, see Rickard, 2007), and thus this issue is a limitation of theories of automaticity more generally. On the other hand, given that memory-based accounts of automaticity assume that basic memory processes underlie speed-ups with practice, they afford the sensible addition of a forgetting parameter to reflect negatively accelerated forgetting of prior interpretations over time (cf. Rubin & Wenzel, 1996). We doubt that memory-based processing theorists would quarrel with this additional assumption, and we realize that forgetting parameters were not included in these theories for the sake of simplicity. However, extending these theories to more complex, real-world tasks in which items typically repeat across days or weeks will likely require surrendering some simplicity for an increase in explanatory power. At least for text comprehension processes, forgetting is likely to be a significant factor influencing the extent to which memory-based processing underlies performance, considering the typical time intervals between repetitions of a given unit of information in language.

Implications for Theories of Comprehension Processes

Thus far, we have considered how theories of automaticity fare with respect to the current results. How do the current results bear on specific theories of conceptual combination? On one hand, the memory-based processing account of the current findings is largely consistent with theories of conceptual combination that assume that the meanings of familiar combinations are lexicalized, or stored in the lexicon as integrated units of information that are activated when a familiar combination is encountered (e.g., Gerrig, 1989; Gerrig & Bortfeld, 1999). However, the memory-based processing account may benefit these theories by articulating the underlying mechanisms and representations involved in the transition of combinations from unfamiliar to familiar and may support further integration of the literatures on novel combination processing and familiar combination processing.

On the other hand, the current findings are less consistent with theories of conceptual combination that assume familiar combinations are processed via the same basic algorithms involved in the interpretation of novel combinations. In particular, our findings weigh against CARIN, at least as currently formulated. To revisit, CARIN (Gagné & Shoben, 1997) assumes that the processing of both novel and familiar combinations involves the selection of a thematic relation that guides an inference about how the two constituents of the combination are related. Candidate relations compete for selection, with competition influenced by the relative frequencies of the various relations associated with the modifier noun. Of concern here is how processing of the repeated subordinate items changes with practice. Given the strong dominant bias for the items used here, reversing the relative frequencies of the dominant and subordinate thematic relations associated with the modifier nouns would almost certainly require more than two or three presentations of the subordinate meaning (recall that reading times converged statistically in the repeated subordinate and dominant conditions as early as Block 3).

More recently, the recency of relation use has also been proposed to influence relation selection (e.g., Gagné & Spalding, 2004). However, it is unclear whether CARIN can account for the current findings even with this additional assumption, because the model does not currently specify how recency and frequency information are weighted in the relation selection process or the persistence of recency effects. At a minimum, CARIN would need to assume that a few (here, 2–3) recent uses of a subordinate relation would be sufficient to override the strong frequency bias favoring the dominant relation for a particular modifier noun. Additionally, to account for the results of Experiment 3, CARIN must further assume that any overriding of the frequency bias persists across days. Gagné and Shoben (2002) found that the presentation of a prime combination involving the same relation as a target combination influenced meaning selection and speed of processing for the target. However, Gagné and Shoben used equibiased target combinations (with two similarly plausible interpretations), as opposed to the strongly biased items used here; and, importantly, targets were presented shortly after primes. Thus, these data do not establish that a recent subordinate prime can override a strong relation-frequency bias or that the effect would persist across delays of up to several days. In sum, CARIN will require further specification and testing to support any claims that interpretation of repeated items here continued to be based on the relation-selection algorithm. More generally, this discussion highlights how the present results can constrain theory and guide further theory development within the conceptual combination literature.

In addition to specific theories of conceptual combination, the present research can inform other theories of comprehension processes more generally. At the highest level, this work recommends a more powerful approach for conceptualizing and investigating automaticity than has conventionally been used in the text comprehension literature. That is, whereas property-list accounts have been used almost exclusively to define automaticity in comprehension research, process-based accounts of automaticity are more likely to further our understanding of the automatization of text comprehension processes by motivating research that investigates how the execution of comprehension processes changes with practice. One way in which increased attention to changes in comprehension processing will benefit theories of comprehension is by remedying the apparent disconnect between different theories within an area. Within the literature on a given component process (e.g., conceptual combination, word meaning), one set of theories may address how novel stimuli are processed (e.g., Chaffin, Morris, & Seely, 2001; Costello & Keane, 2001; Estes, 2003; Wisniewski & Middleton, 2002), whereas a different set of theories addresses how familiar stimuli are processed (Andrews, Miller, & Rayner, 2004; Duffy, Morris, & Rayner, 1988; Juhasz, Starr, Inhoff, & Placke, 2003; Vu, Kellas, Metcalf, & Herman, 2000). Process accounts of automaticity can provide the missing link between these two kinds of theory, yielding a more complete understanding of the processing involved as stimuli transition from novel to familiar and the relative contributions of algorithm and retrieval to the processing of different stimuli within the same component system.

Incorporating memory-based processing accounts of automaticity into text comprehension theories accords with an emerging emphasis on memory-based views of text comprehension (e.g., McKoon & Ratcliff, 1998; Myers & O'Brien, 1998). For example, McKoon and Ratcliff (1998) have suggested that the processing of words, concepts, and propositions in a text can involve the activation of information in long-term memory via a direct-access form of retrieval referred to as *resonance*. Similarly, Myers and

O'Brien (1998) proposed a *resonance model* to specify how concepts and propositions in the sentence currently being processed send a signal to other elements in long-term memory (from earlier in the text representation and/or from prior knowledge) and the factors that influence the strength of this signal. Although arguably a cousin to memory-based theories of automaticity, the resonance model was proposed as a model of knowledge activation and thus is understandably silent on questions concerning the nature and development of automaticity.

McKoon and Ratcliff (1998) point out that "we currently know almost nothing about the boundaries between resonance and other comprehension processes. Delineating the tasks served by memory from other, more constructive processes is an important task for future research" (p. 34). The memory-based processing account of automaticity provides one way to conceptualize this boundary and makes straightforward claims about how and when memory is involved in text comprehension processes. Specifically, one precondition for the involvement of memory-based processing in the automatization of a component process in the text comprehension system is that specific information units processed by that component repeat within the language. Accordingly, memory-based processing is likely to make its largest contribution to the automatization of lower-level comprehension processes (e.g., processes involved in word form recognition, word meaning, syntactic parsing, semantic parsing), because these processes handle relatively small units of information that repeat frequently in the language (e.g., words, phrases). Although memory-based processing is likely to play a lesser role in the automatization of higher-level comprehension processes (e.g., inferencing) because they deal with larger units of information that repeat less frequently, memory-based processing may still make an indirect contribution to the operation of these processes. If one assumes that the various component processes involved in the text comprehension system must share processing resources (Rawson, 2007), then the shift from algorithmic processing to greater reliance on memory-based processing in lower-level components may free up processing resources for the more successful operation of higher-level processes. Furthermore, for cases in which the output of one component process informs processes at other levels within the system, to the extent that this output is generated more quickly when based on retrieval versus algorithmic processing, other processes will receive their input more quickly and thus may generate their own outputs more quickly.

In sum, the present research provides relatively strong evidence for the involvement of memory-based processing in the automatization of conceptual combination during text comprehension, providing an important theoretical and empirical advance to understanding the nature of automaticity in text comprehension processes.

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(*Appendix follows*)

Appendix

Conceptual Combinations With the Disambiguating Regions Containing the Subordinate and Dominant Meanings

Table A1

	Disambiguating Region	
Combination	Subordinate	Dominant
bee spider	that only ate bees	that looked like a bee
firecracker temper	when kids played with firecrackers	as quick as a firecracker
bullet sprinter	with a jersey advertising bullets	who was as fast as a bullet
chocolate lizard	lizard that was the color of chocolate	chocolate that was the shape of a lizard
flu liquid	to spread the flu	to cure the flu
cheetah bike	tan and spotted	really fast
job tension	really needed to find a job	was very stressed at his job
giraffe gazelle	that lived with a herd of giraffes	with a long neck like a giraffe
mouse bats	only ate small field mice	was small and looked like a mouse
paper dog	trained to fetch the paper	made out of paper
mourner musician	also a mourner at the funeral	hired by mourners to play at funerals
radish car	the car she used to take radishes	a small radish-colored car she drove
earthquake divorce	happened during an earthquake	were as violent as an earthquake
razor insults	made fun of the girl's pink razor he had	called him names that cut like a razor
mountain flag	with the mountain emblem of their team	they were to plant at the mountain top
robin fish	that robins will catch and eat	with bright red bellies like robins
seesaw relationship	was best when playing on the seesaw	went up and down like a seesaw
shark virus	attacked her viciously like a shark	attacked the sharks she was studying
skunk mud	had a dead skunk in it	was as stinky as a skunk
stone ladder	the thick rope ladder for scaling stone walls	the ladder chiseled into a stone wall
tiger chair	that had been used by famous tiger trainers	that was entirely covered in tiger print
watch necklace	that matched her watch perfectly	with a watch in the pendant
winter flowers	that were the color of winter frost	that only grow and bloom in winter
yarn truck	that his grandma had knitted out of yarn	that delivered yarn to the craft store
zebra tie	with cartoon zebras on it	with black and white zebra stripes
banana cucumbers	that peel like bananas	that look like bananas
lemon apples	bright yellow like a lemon	quite sour like a lemon
vampire flies	unless repelled with garlic	and bite bare necks to suck blood
cooking remedies	prepare medicines at home	improve boring recipes
monkey thieves	the monkeys who stole all the food	the activists who stole the monkeys

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