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Bias in Auditory Priming

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Priming for previously studied words in an implicit auditory memory task has been interpreted as evidence for a presemantic perceptual representation system that encodes acoustic representations of words (B. A. Church & D. L. Schacter, 1994). In this article, 3 experiments provided evidence that such priming may result instead from a bias to respond with studied words. In forced-choice identification with similar alternative choices, there was no overall improvement in performance due to prior study. Benefits for studied test words were offset by costs for similar but nonstudied test words. Prior study had no effect when forced-choice alternatives were dissimilar. The data are discussed in relation to current models of auditory information processing and a new model (R. Ratcliff & G. McKoon, in press) for priming in visual word identification.

Research aimed at documenting and understanding how memory affects performance on implicit memory tasks has been the focus of considerable attention recently. In implicit memory tasks, participants are not explicitly asked to retrieve information about prior encounters with stimuli, yet their performance is often affected by those encounters. The experimental findings driving this area of research are the long-term repetition priming effects that have been observed in a number of implicit memory tasks, the dissociations of these priming effects from performance on explicit memory tasks, and the preservation of the effects under amnesia. The findings have been viewed as demonstrating the existence of a perceptual representation memory system, which has the function of supporting the processing of information about the form and structure of a stimulus. For example, a *structural description subsystem* has been suggested as supporting the perception of three-dimensional objects (Cooper & Schacter, 1992; Schacter, 1994; Schacter, Cooper, & Delaney, 1990; Schacter, Cooper, Delaney, Peterson, & Tharan, 1991; Schacter, Cooper, & Treadwell, 1993; Schacter & Tulving, 1994; Tulving & Schacter, 1990) and a *visual word form subsystem* has been suggested as supporting the perception of words (Graf & Schacter, 1985; Schacter, 1990, 1994; Schacter, Chiu, & Ochsner, 1993; Warrington & Shallice, 1980).

Experiments demonstrating repetition priming effects for auditory stimuli are the topic of this article. Priming effects for auditorily presented words have been offered as evidence for the existence of an implicit *presemantic auditory subsystem* (Schacter & Church, 1992). When participants are asked to identify a word presented in noise, their accuracy is facilitated by previous exposure to the word. A similar effect is observed in auditory stem completion; participants are more likely to complete an auditory word stem with a word that they have heard previously (Church & Schacter, 1994; Schacter & Church, 1992). Schacter and Church (1992; Church & Schacter, 1994) proposed that the auditory perceptual representation system was responsible for these effects and argued that the system was distinct from episodic memory because of dissociations between the effects of some variables on priming in the implicit memory tasks versus performance on explicit memory tasks. Encoding task manipulations that affected performance on explicit memory tests, such as level of processing, did not affect the amount of priming on implicit tests. Likewise, changes in perceptual characteristics of stimuli from study to test (such as changes in prosody, fundamental frequency, or speaker) that decreased priming on implicit memory tasks had no effect on explicit memory tests (Church & Schacter, 1994; Schacter & Church, 1992). In addition, experiments with brain-damaged participants demonstrated intact auditory priming even for individuals who perform very poorly on tests of explicit memory (Schacter, Church, & Bolton, 1995; Schacter, Church, & Treadwell, 1993; but see Jernigan & Ostergaard, 1993).

According to Church and Schacter (1994), perceptual representation systems are cortically based memory systems separate from the hippocampal system that is assumed to be responsible for explicit retrieval. In their account, perceptual representation systems are responsible for storing a modality-specific representation of the perceptual features of an incoming stimulus. Dissociations between implicit and explicit tests of memory are said to result from the fact that the perceptual representation systems store perception-based representations, whereas the explicit memory system is primarily devoted to semantic or associative forms of representation. If the auditory perceptual representation subsystem were purely perceptual, storing only acoustical information, then one would predict that large changes in the acoustical properties of a stimulus between study and test

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(such as being spoken by a male voice vs. a female voice) would eliminate priming for that item. Because Schacter and Church (1992) found instead that such changes sometimes reduce but never eliminate priming, they speculated that there may be two auditory perceptual representation subsystems, one storing purely acoustical information and another storing phonological representations (Church & Schacter, 1994; Schacter & Church, 1992). They hypothesized that the second, more abstract subsystem was responsible for the priming that was still observed after a change in speaker, intonation, or fundamental frequency. Observing that Schacter et al. (1995) did not find with amnesic participants the decreased priming as a result of changes in speaker's voice that had previously been observed with normal participants, Church and Schacter (also Schacter et al., 1995) further speculated that voice-specific priming may require the use of the episodic system to somehow integrate representations from the two auditory subsystems at the time of the test. Presumably, amnesics' performance on a test item would be influenced only by the more abstract acoustic representation, whereas normal participants' performance would reflect the influence of both abstract and voice-specific information that resulted from the integration of the two representations for the item. In this account, we are left with two implicit memory subsystems to explain auditory priming, and perhaps with the requirement of intervention from the explicit memory system as well.

Repetition priming effects for the perceptual identification of auditorily presented words are similar to those for visually presented words: Previous exposure to a word facilitates later naming of the word (Broadbent, 1967; Ellis, 1983; Jackson & Morton, 1984; Kempley & Morton, 1982; Morton, 1968). Ratcliff and McKoon (in press) and Ratcliff, McKoon, and Verwoerd (1989) have shown that for visually presented words, the priming effect is a bias effect (see Broadbent, 1967; Morton, 1968; Norris, 1995). Previous exposure to a word gives benefits on later tests of that same word but hurts performance on later tests of a similar but different word. Bias effects have also been shown with other implicit memory tasks, including picture naming, object decision, stem completion, and fragment completion (McKoon & Ratcliff, 1995; Ratcliff & McKoon, 1995, 1996, in press).

Priming as a bias effect is inconsistent with the accounts of priming that have been offered for the perceptual representation subsystems. Tulving and Schacter (1990) have argued that the perceptual representation system plays an "important role in identifying words and objects" (p. 301) and that it "operates at a presemantic level" (Schacter & Tulving, 1994, p. 28) to improve perceptual processing. In the visual domain, Schacter (1994, p. 237) has stated that previous exposure to a word "may make it easier for the PRS [perceptual representation system] mechanisms involved with visual word form representation to extract visual information from the test cue or generate the target item" (p. 237). If perceptual information is extracted more easily, then one would expect an overall improvement in performance. However, with a bias effect of costs about equal to benefits, there is no such improvement.

This article reports experiments that were designed to determine whether the priming effect in auditory word identification is a bias effect similar to that found with visual stimuli (Ratcliff & McKoon, 1996, in press; Ratcliff et al., 1989). The hypothesized role of the auditory perceptual representation system in priming has not been clearly stated. Because it is one of the perceptual representation subsystems, it might be expected to support priming in the same way as the other subsystems, that is, by improving perceptual processing. Consistent with this, Church and Schacter (1994) have said that "there may be two perceptual representation subsystems contributing to auditory priming, one that represents abstract phonological information and another that represents specific acoustic information" (p. 531). However, Schacter and Church and their colleagues (Church & Schacter, 1994; Schacter & Church, 1992; Schacter, Church, & Treadwell, 1993; Schacter et al., 1995) are most often mute on the specific mechanisms that underlie priming for auditory stimuli. They typically do not provide any description of these mechanisms. So it is possible that the account of priming as an improvement in performance applies only to the visual perceptual representation subsystems, not to the auditory subsystem.

The experiments reported here were designed to examine bias with auditory stimuli in the same way as Ratcliff et al. (1989) examined bias in the visual domain, by using a forced-choice procedure. In earlier research, the typical implicit memory task (Jacoby, 1983a, 1983b; Jacoby & Dallas, 1981) had been to identify a word by naming it. In the first phase of an experiment, participants studied a list of words, and in the second phase, they were presented with a series of target words. Each target was flashed for a brief amount of time, and participants were asked to name it. In Ratcliff et al.'s procedure, forced choice was substituted for naming. After the target was flashed, two alternatives were presented, and participants were asked to indicate which of them was the same as the flashed target. One of the alternatives was the target that had actually been flashed, and the other was a word highly similar to the target. If it was improved perceptual processing that caused prior presentation of a target in the study list to increase accuracy on naming identification, then there should have been increased discrimination between the forced-choice alternatives. Instead, Ratcliff et al. (also Ratcliff & McKoon, in press) found that prior study produced bias. Participants were more likely to choose the alternative that had been studied both when it matched the flashed target (a correct response) and when it was only similar to it (an incorrect response). In addition, Ratcliff et al. found that there was no effect of prior exposure at all when the two forced-choice alternatives were dissimilar from each other. This finding also indicates that prior exposure to a perceptual stimulus does not improve perceptual processing. The experiments reported here followed the same experimental designs with auditory presentation of words as Ratcliff et al. had used for visual presentation of words.

Ratcliff and McKoon (in press) presented a counter model for bias in visual perceptual identification that deals with data from identification by naming and identification by forced-choice tasks. The model is related to other word-identification models such as the logogen model (Morton, 1969, 1970, 1979) and the interactive activation model (McClelland & Rumelhart, 1981) in that responses are initiated when word units or counters accumulate sufficient information to exceed a threshold value. In Ratcliff and McKoon's account, priming effects are modeled by the counters corresponding to previously studied words attracting more information than they otherwise would. The experiments here were designed to determine whether priming effects in the auditory domain show the same empirical pattern of bias as in the visual domain and therefore can potentially be explained by the counter model.

We began with a replication of the priming effect in auditory identification to demonstrate that our materials and equipment allowed us to produce the same results as Schacter and Church (1992). Participants heard a list of words in the study phase of the experiment, and then they were presented with target words mixed with computer-generated white noise in the test phase. They were asked to name each target word. We replicated priming in that participants were better able to name a word that had been presented in the study phase. We also included in our design a condition that Schacter and Church did not, a condition in which the previously studied word was similar but not identical to the target test word. For example, if *sunk* was studied, the target test word might have been *sung*. We thought there might be some small costs associated with study of a word similar to but not the same as the target test word, even though identifying a word by naming it is not as sensitive as identifying it in forced choice for showing the costs associated with bias (see Ratcliff & McKoon, in press; Ratcliff et al., 1989). In Experiments 2 and 3, after replicating priming in Experiment 1 with identification by naming, we switched to forced choice.

Experiment 1

Method

Participants. The participants for the experiment were 24 Northwestern University undergraduates participating either for pay or to fulfill a course requirement. Participants were tested in groups of 1 to 4.

Materials and apparatus. Sixty pairs of similar-sounding words were chosen as stimuli for the experiment. The pronunciations of the words in each pair differed from each other by only one or two phonemes. The phonemes that differed within a pair were either stop consonants (/p/, /t/, /k/, /b/, /d/, and /g/) or weak fricatives (/f/, /T/, /v/, /D/, and /h/). We chose words differing in only these consonants so that they would be difficult to distinguish in a background of white noise. All of the words in this experiment were either one or two syllables, and within each pair of two-syllable words, the accent fell on the same syllable for both words (see Appendix).

The stimuli were spoken by a female speaker and recorded on a cassette tape. They were then digitized on a NeXT workstation at a sampling rate of 8,012 Hz and in some cases were edited with a waveform editor (edsnd version 1.4) to ensure that the words in each pair sounded reasonably similar to each other. The editing consisted of cutting and pasting vowel sounds from one word in the pair to the other to ensure that the vowels sounded similar in the two words and of adding or deleting silence or frication for stop consonants that were either too easy or too difficult to discriminate as they were originally spoken. For the test phase, the words were mixed with computer-generated white noise. The white noise was generated with Paul Lansky's cmix program on the NeXT. Presentation of the stimuli was controlled by the NeXT workstation connected to an amplifier and four sets of headphones. The relative amplitudes of the noise and the test words were adjusted experimentally so that performance was at neither floor nor ceiling, and the overall amplitude was adjusted on the amplifier to a comfortable listening level.

Design and procedure. The experiment consisted of a study phase followed immediately by a test phase. In the study phase, 40 words were presented, and participants were instructed to rate how clearly each word was pronounced using a scale of 1 to 5. This is essentially the same as the nonsemantic encoding task used by Schacter and Church (1992, Experiments 4 and 5). Participants recorded their responses on a sheet with lines numbered 1 to 40. The words were presented binaurally with 7 s between each word. An interval of approximately 2 min separated the study and test phases, and during this interval participants were given instructions for the test phase. No mention was made of any relationship between the two phases of the experiment.

In the test phase, 60 words (1 from each of the 60 pairs) were presented for identification. Each test word was presented binaurally over the headphones, masked by white noise, and participants were instructed to write down the word that they heard on each trial. Participants recorded their responses on a sheet with lines numbered 1 to 60. They were told to place an *x* on the line if they could not tell what the word was. Seven seconds intervened between each test word. The duration of the white noise masking the test word was 3 s, with the onset of the noise occurring at least 1 s before the onset of the word and the offset of the word occurring at least 1 s before the offset of the noise.

In the test phase, 20 of the test words had been presented during the study phase (the study–target condition). For another 20 of the test items, the test word had not been presented during the study phase, but a similar-sounding word had been (study–similar). For the remaining 20 test words, neither member of the pair had been presented in the study phase (study–none). For the pair of words *sung* and *sunk*, for example, a participant who heard the word *sung* in the test phase could have heard *sung* (study–target), *sunk* (study–similar), or neither (study–none) in the study phase. The 60 items and 24 participants were combined in a Latin square design, counterbalancing study condition (target, similar, or none) and which member of each pair was presented for identification across subjects and items. Six different random orderings of study items and of test items with equal numbers of participants per ordering were used in the experiment.

Results

Participants' responses in the test phase were assigned to one of three categories: correct responses, intrusions of the similar-sounding word for the target, and other errors. If the word written by the participant was the target word that was actually presented in the test phase or was a homophone of that word, it was scored as correct. If the participant responded with the word (or a homophone of the word) that was similar to the target word, it was scored as a similar intrusion. For example, if the target presented in the test phase was *sung*, a response of *sung* was scored as correct and a response of *sunk* was scored as an intrusion of a similar word (regardless of whether *sung* or *sunk* had been the studied word). If the response was any other word than the target, its similar-sounding pair mate, or a homophone of one of them, it was simply scored as an error, as were trials in which participants made no response. Table 1 presents the proportion of correct responses, intrusions of similar words, and errors plus omissions for each of the three study conditions in Experiment 1. Overall, the data closely parallel the results of experiments with visually presented words (Ratcliff et al., 1989; Ratcliff & McKoon, in press).

For correct target responses, prior study of the target improved performance and prior study of the similar word slightly hurt performance. The proportions of correct responses in each study condition for subjects (F_1) and for items (F_2) were entered into separate one-way analyses of variance (ANOVAs), which included counterbalancing assignment as a variable. Study condition (target, similar, or none) was a within-subjects and within-items variable in the analyses. For all reported F values, $p < .05$ unless otherwise noted. The main effect of study condition was reliable by both subjects and items, $F_1(2, 36) = 29.06$, $MSE = 0.0068$; $F_2(2, 108) = 25.37$, $MSE = 0.0194$. Planned comparisons using single degree of freedom contrasts confirmed that the study–target condition produced a greater proportion of correct responses than the baseline study–none condition, $F_1(1, 36) = 27.23$, $MSE = 0.0068$; $F_2(1, 108) = 19.27$, $MSE = 0.0194$. The proportion of correct responses in the study–similar condition was slightly lower than in the baseline condition, although this difference was not statistically reliable, $F_1(1, 36) = 1.30$, $MSE = 0.0068$, *ns;* $F_2(1, 108) = 1.13$, $MSE = 0.0194$, *ns*. In visual experiments (Ratcliff & McKoon, in press; Ratcliff et al., 1989), the proportion of correct responses in the study–similar condition was sometimes a little lower than baseline and sometimes a little higher.

As with correct responses, similar intrusions showed that participants tended to respond with a word they had heard earlier. The proportion of intrusions increased in the study–similar condition relative to baseline and decreased (marginally) in the study–target condition. The proportions of similar intrusions were analyzed in the same way as the proportions of correct responses. There was a reliable main effect of study condition, $F_1(2, 36) = 10.49$, $MSE = 0.0036$; $F_2(2, 108) = 7.57$, $MSE = 0.0125$, with more intrusions occurring in the study–similar condition than in the baseline condition, $F_1(1, 36) = 6.38$, $MSE = 0.0036$; $F_2(1, 108) = 4.50$, $MSE = 0.0125$. There were fewer intrusions for the study–target condition than for the baseline, $F_1(1, 36) = 4.18$, $MSE = 0.0036$, although this difference was only marginal in the items analysis, $F_2(1, 36) = 2.95$, $MSE = 0.0125$, $p < .09$.

Experiment 2

The results of Experiment 1 replicated Schacter and Church's (1992) finding of facilitated recognition for previously heard words, but in addition, the results suggest that the effect of prior exposure could be one of bias, not a general improvement in perceptual processing. As the result of prior study of a word similar to but different from the target, there was a significant increase in the number of incorrect, intrusion responses. The aim of Experiment 2 was to examine the effect of prior exposure by using a forced-choice identification procedure, a procedure more likely to show both costs and benefits than identification with naming (following Ratcliff et al., 1989).

Method

Participants. The participants for Experiment 2 were 36 Northwestern University undergraduates who participated in fulfillment of a requirement for an introductory psychology course.

Materials and apparatus. The pairs of words from Experiment 1 were used as stimuli in this experiment. Three additional words served as practice stimuli preceding the test phase. The only other differences in materials between Experiments 1 and 2 were the addition of the visually presented pairs of words in the forced-choice test and an increase in the level of noise masking the words in the test phase for Experiment 2. The noise level was adjusted experimentally until it was judged to be at a level that would not produce ceiling effects. The increased noise level was necessary because the level used in Experiment 1 was likely to result in near ceiling performance in the easier forced-choice identification task. Study words were presented through headphones in the same way as for Experiment 1. Pairs of words for forced choice were presented on the screen of a 286 personal computer (PC), and participants used the keyboard to record their responses. The presentation of the visual and auditory stimuli was coordinated through a series of timing pulses on a second output channel from the NeXT. At the offset of each spoken word that was presented for an identification judgment, a timing pulse from the NeXT was sent to the game port of the PC, triggering the visual presentation of the two forced-choice identification alternatives on the screen.

Design and procedure. The design of Experiment 2 was similar to that of Experiment 1, with 40 words presented in the study phase and 20 words from each study condition (study–target,

Table 1
Identification Results for Experiment 1

Study condition	Test word	Probability of correct target response	Probability of similar intrusion	Probability of an error or omission
Target word	Target	.390	.052	.558
Similar word	Target	.221	.131	.648
No study	Target	.248	.087	.665

Note. Of all responses, .262 were omissions, so .362 of all responses were errors that were not intrusions.

study–similar, or study–none) presented in the test phase, again combining participants and items in a Latin square design. For all three study conditions, the forced-choice alternatives presented after the flashed target were the target and its pair mate, that is, the word similar to the target.

The study phase was identical to the study phase of the first experiment, with participants again rating how clearly each word was pronounced. Two minutes after the study phase ended, the test phase began. In the test phase, participants heard a word masked by white noise and then made a forced choice between two visually presented words to identify the spoken word.

The procedure for the forced-choice test was as follows. First, a row of plus signs was displayed in the center of the computer screen. The target test word for the first practice item was then presented over the headphones, masked by white noise. The onset of the test word occurred at least 1 s after the onset of the noise, and the noise lasted a total of 3 s, continuing for at least 1 s after the test word ended. As soon as the test word ended, a timing pulse from the NeXT caused the row of plus signs on the screen to be replaced by two words, printed side by side in the center of the screen, one the target test word and the other its similar pair mate. The participant then pressed a key to indicate which of the two words on the screen he or she had heard on the headphones. Participants pressed the ?/key for the word on the right and the Z key for the word on the left. The words remained on the screen until the participant responded or until 2,500 ms had elapsed. When the participant pressed a key, the screen was cleared for the remainder of the 2,500 ms, and then a row of plus signs appeared. If a participant failed to respond within 2,500 ms, the words disappeared from the screen and were immediately replaced by the row of plus signs. Seven seconds after the beginning of the first practice item, the second practice item was presented. Thirty seconds after the third practice item, the experimental test words were presented using the same procedure as the practice items. Participants were not informed of any relationship between the test items and the words in the study phase.

Results

Table 2 displays the proportion of correct responses for each of the three study conditions in Experiment 2. Study condition (study–target, study–similar, or study–none) was a within-subjects and within-items variable. The main effect for study condition was reliable by both subjects and items, $F_1(2, 60) = 12.32$, $MSE = 0.0077$; $F_2(1, 108) = 9.14$, $MSE = 0.0174$. When participants had heard the test word in the study phase, the test word was more likely to be identified correctly compared with the no-study baseline condition: planned comparison, $F_1(1, 60) = 5.50$, $MSE = 0.0077$; $F_2(1, 108) = 4.09$, $MSE = 0.0174$. When the test word had not been heard in the study phase but a similar-sounding word had been, however, performance in the identification test was worse than in the baseline condition, $F_1(1, 60) = 6.83$, $MSE = 0.0077$; $F_2(1, 108) = 5.07$, $MSE = 0.0174$. Although having heard a word in the study phase helped identification performance for the studied words, it also hurt performance for similar-sounding words by about the same amount.

It might be thought that the results could be explained by a slow strategic process that was brought to bear when a word was not identified, a process by which information from explicit memory was examined. To test this possibility, we divided the data into responses faster than the median and responses slower than the median. The results for the fast responses showed a slightly larger bias pattern (baseline, .63; study–similar, .55; study–same, .71), and the slow responses showed a reduced effect (baseline, .58; study–similar, .55; study–same, .60). So the bias effect is present early in processing, and an explanation by which the bias effect is obtained from slow strategic processes can be ruled out.

Experiment 3

The results of Experiment 2 show that prior exposure did not lead to an overall improvement in performance on forced choice. Instead, performance showed balanced costs and benefits, indicating a bias interpretation of priming. Although Experiment 2 did not examine the full range of experimental manipulations (such as changes in the voice of the speaker for the studied and tested words) that Schacter, Church, and their colleagues (Church & Schacter, 1994; Schacter & Church, 1992; Schacter, Church, & Treadwell, 1993; Schacter et al., 1995) have performed, the bias finding provides a critical constraint on how the basic priming effect can be understood.

An equally important constraint can be provided by a

Table 2
Forced-Choice Results for Experiments 2 and 3

Experiment and type of alternative	Study condition	Test word	Probability correct	Probability of an error	Probability of a time-out
Experiment 2: Similar alternatives	Target word	Target	.653	.335	.013
Experiment 2: Similar alternatives	Similar word	Target	.550	.429	.021
Experiment 2: Similar alternatives	No study	Target	.604	.382	.014
Experiment 3: Dissimilar alternatives	Target word	Target	.762	.223	.015
Experiment 3: Dissimilar alternatives	Dissimilar word	Target	.756	.227	.017
Experiment 3: Dissimilar alternatives	No study	Target	.756	.229	.015

procedure in which the two alternatives for forced choice are dissimilar from each other. If priming were the result of improved perceptual processing, then performance should be facilitated irrespective of whether the alternatives are similar or dissimilar, but for visually presented words, Ratcliff et al. (1989; see also Ratcliff & McKoon, in press) found no effect of prior study at all when the forced-choice alternatives were dissimilar. They used this as strong evidence to guide development of a theoretical account of priming. In Experiment 3, we applied the same test to auditory priming.

Method

For Experiment 3, one of the members of each of the 60 pairs of similar-sounding words used in the first two experiments was replaced with a dissimilar word. The dissimilar words differed from words in the original similar pair in easily distinguishable features such as accent patterns, number of syllables, or vowels. The materials, design, and procedure for Experiment 3 were otherwise identical to those of Experiment 2, with one member of each pair presented auditorily in the forced-choice test and both words of the pair appearing on the computer screen for the participant to choose between. Again, 40 words were presented auditorily in the study phase and rated for clarity of pronunciation. Twenty-four Northwestern University undergraduates participated in the experiment, either for pay or in fulfillment of a course requirement.

Results

The proportions of correct responses in Experiment 3 are shown in Table 2. The forced choice was between two words that were not phonologically similar, and in this case, it made no difference whether or not the test word had been heard in the study phase. There was neither improved performance in the study–target condition nor worse performance in the study–dissimilar condition compared with the no-study baseline, $F_1(2, 36) < 1$, $MSE = 0.0073$, *ns*; $F_2(2, 108) < 1$, $MSE = 0.0380$, *ns*. The statistical power to detect a difference among the three means, which was the same size as those in Experiment 2, is .94. With about 75% of the responses correct, there are no problems with possible ceiling (100% correct) or floor (50% correct) effects. Also, conditionalizing on response speed showed that there was no effect of study condition on responses faster than the median or on responses slower than the median.

The data of Experiment 3 are important in that they show that prior study did not improve performance. In fact, not only did prior study not improve performance, it did not affect it in any way at all. This indicates that participants were not using explicit episodic information about previous study of a word to decide their response. If they had been using a strategy dependent on episodic information, then it would be expected that they would have tended to choose the alternative previously studied, but the data did not show such a tendency. This finding is the same as in the visual domain, where with dissimilar forced-choice alternatives, there was no effect of prior study, even when similar forced-choice tests were mixed with the dissimilar tests and when identification with naming and forced choice were mixed within an experiment (Ratcliff & McKoon, in press).

General Discussion

Experiment 1 replicated the auditory priming result found by Schacter and Church (1992) that identification of a word presented in noise was facilitated by prior presentation of the word. However, Experiment 1 also showed a potential cost: Prior presentation of a word similar to but different from the target led to intrusion errors in identification. Experiment 2, with a forced-choice procedure, showed that the costs due to prior study of a word similar to but different from a target balanced out the benefits of prior study of the target. This bias effect was shown by Experiment 3 to be limited to a choice between similar words; for forced choice between two dissimilar words, there was no effect of prior study at all. The overall pattern of these results is conceptually the same as was reported by Ratcliff and McKoon (in press) and Ratcliff et al. (1989) for visually presented stimuli. The results also extend the general finding of bias in implicit memory tasks. Ratcliff and McKoon (1995, 1996) showed that priming effects in object decision, picture naming, and stem and fragment completion can all be interpreted as bias effects; when a test item was studied earlier, performance was improved, but when an item similar to the test item was studied earlier, performance was reduced by about the same amount.

The challenge is what kind of theoretical approach to take to explain bias. The currently dominant approach is to use priming effects, dissociations from explicit memory tasks, and data from amnesic patients to guide a qualitative account that postulates separate memory systems. Taking this approach, one suggestion has been that priming is the result of previously established representations in the memory systems (Church & Schacter, 1994; Schacter & Church, 1992). Although these representations might be expected to improve perceptual processing (Schacter, 1994; Tulving & Schacter, 1990), our data show that with similar forced-choice alternatives, the benefit of prior exposure is offset by costs, and with dissimilar alternatives, there is no benefit or cost from prior exposure at all. Even if the perceptual representation system proposal were to make predictions about bias instead of facilitation, it would be expected to predict an effect on processing of prior study when the two test alternatives were dissimilar.

One alternative to the postulation of separate memory systems is Roediger's proposal of transfer-appropriate processing (e.g., Roediger, 1990; Roediger, Weldon, & Challis, 1989). The hypothesis is that performance on a memory test benefits from prior study to the extent that the cognitive operations used at test overlap those used at study. A number of experimental results have been interpreted as consistent with this hypothesis, and it serves as a competitor for the memory systems view. However, as with the memory systems view, transfer-appropriate processing offers no explanation of the bias effects obtained in the experiments reported here or in other implicit memory experiments (Ratcliff & McKoon, 1995, 1996, in press; Ratcliff et al., 1989). Also, it is not clear how transfer-appropriate processing could predict why the pattern of priming varied exactly as it did as a function of the identification task (naming vs. forced choice) and the type of distractors in forced choice.

The approach we support is to attempt to explain priming in implicit memory tasks with information processing models such as, for example, Ratcliff and McKoon's (in press) counter model, Morton's (1979) logogen model, McClelland and Rumelhart's (1981) interactive activation model, or McClelland and Elman's (1986) model. Morton (1970) explicitly argued that repetition effects (now called priming effects in implicit tasks) were a by-product of the main functions of information processing mechanisms. In this view, models should be designed to perform the main function of word identification, and mechanisms to produce priming effects should be added to these models (if necessary). For example, the counter model developed by Ratcliff and McKoon (in press) accounts for bias effects for visually presented words in identification with naming and with forced choice (with similar and dissimilar alternatives in forced choice), and it can also be applied to the bias effect for auditory presentation of words.

The counter model is a random walk in which decision counters that correspond to words accumulate counts. A response decision is reached when the total number of counts in one counter exceeds the maximum of all the others by a criterial amount. The decision process is assumed to be continuous, with one count entering the system for each unit of time. The decision process is guided by the results of perceptual analyses. These are also assumed to be available continuously, but under the suboptimal identification conditions of a perceptual identification experiment, there are some units of time for which perceptual information is not available to guide the decision process. For a unit of time for which information is available, the count for that time unit is accumulated by the counter for a word consistent with the information. For a unit of time for which perceptual information is not available to guide the decision process, the count is accumulated by some random counter; this is called a *null count* (this can also be thought of as random noise in the system).

The basic assumption of the model to explain priming is that the counter for a previously studied word becomes an attractor: It attracts null counts and counts ambiguous between it and other similar words. The counter interprets these counts as positive evidence for itself with a slightly greater probability than would be the case if the word had not been previously studied. The attractive force is assumed to extend only through the neighborhood of words similar to the previously studied word, so it takes counts away from words similar to it but not from words dissimilar to it. This explains why there is a bias for similar alternatives in forced choice but not for dissimilar alternatives. We use the words *attractive force* as a metaphor for the quantitative formulation of the model that is fully presented in Ratcliff and McKoon (in press). This metaphor should be treated no more seriously than other metaphors (e.g., *spreading activation*).

The assumptions just outlined are sufficient to explain bias. Because the various manifestations of bias are equivalent with auditorily and visually presented words, the counter model can apply to both. Following Morton (1979), there would be two sets of counters, one for visual representations and one for auditory representations. (This separation has been used to explain the small, or insignificant, amount of transfer of priming between modalities).

For forced choice, the counter model assumes that the decision process restricts the accumulation of counts to the two counters for the words presented as alternative choices. A count that corresponds to perceptual information that is consistent with one of the two words but not with the other is accumulated to the appropriate word's counter. If neither word was previously studied, counts consistent with both words and null counts are accumulated to one of the two choices randomly (probability = .50). If one of the choices was previously studied, its counter becomes an attractor. If the forced-choice alternative is similar, the previously studied alternative attracts counts with a probability slightly greater than chance (e.g., .51 instead of .50). However, if the forced-choice alternative is dissimilar, then the previously studied alternative cannot attract counts away from it, and the probability remains at chance (.50).

Quantitative predictions of the counter model for visually presented words closely mirrored the empirical data (Ratcliff & McKoon, in press). In particular, the slight increase in the probability with which a previously studied word attracts counts was sufficient to account for the size of the empirically obtained bias effect for similar alternatives. The fact that the attraction of counts extends only through words similar to the previously studied one explains why there was bias only with similar alternative choices. The model also accounts for the form of the parametric function relating presentation time for the target word and accuracy.

In forced choice, two alternative words are provided to the decision process, but in identification by naming, there are no restrictions; the target word could be any word in the lexicon. The counter model assumes that with naming, a count corresponding to perceptual information can either distinguish a target word from its similar neighbors, in which case the target accumulates the count, or it can be consistent with all of those neighbors but distinguish them from dissimilar words; in this latter case, the count is accumulated by the target or by one of the similar neighbors, chosen randomly. Prior study of a word causes the word to attract more than an equal share of the counts that are consistent with the similar neighbors, and it causes both the word and its similar neighbors to attract more null counts from less similar neighbors than otherwise would be the case. These two increases in probability combine to predict naming data: an increased probability of correctly identifying a target word when it was previously studied; an increased probability of incorrectly identifying a target word as a previously studied, similar word; and little change in the probability of correctly identifying a target word when a similar word was studied.

The model also accurately predicts the probability of correctly naming a word as a function of its frequency and as a function of its number of visually similar neighbors. The number of visually similar neighbors of a word affects its identification in that, the more neighbors, the more competition for counts, and therefore the lower the probability of correct identification. Quantitatively correct predictions for neighborhood effects were demonstrated by Ratcliff and McKoon (in press).

Word frequency is modeled by changes in the resting level number of counts in the counter, with higher frequency words having a higher resting level number of counts than low-frequency words. Because frequency affects the resting level, whereas prior exposure affects the ability to attract counts, the two effects come from different components of the model. In contrast, in Morton's (1969, 1979) logogen model, both effects come from the same component, the resting level number of counts. In Morton's model, decay of priming is assumed to be rapid in order to prevent the resting levels of counters from rising to threshold values (see Morton, 1970, p. 207), but this assumption was contradicted by data showing that priming decayed slowly. By placing priming and frequency in different components, the counter model avoids this problem.

We did not fit the counter model quantitatively to the data from the experiments reported here. There would be more than enough parameters to fit the data because there are insufficient constraints to provide stringent tests. To provide parametric data that allowed tests of the model in the visual domain, Ratcliff and McKoon (in press) used manipulations such as the display time for the target test word and the relationship between performance on the naming and forced-choice identification tasks for individual participants. The aim of this article is to establish the phenomena of bias in auditory priming rather than to perform detailed tests of the counter model.

Unlike the counter model, other models of word identification in their current implementations cannot explain the effects of bias (see Ratcliff & McKoon, in press). For example, if an activation-based model predicts some effect of prior study on forced choice with similar alternative choices, then it must predict an effect with dissimilar alternatives because activation would have to be higher for a previously studied word than baseline, and this would be true no matter what the other alternative. Similarly, Church and Schacter's (1994) proposal that priming for studied words depends on perceptual representation subsystems that represent "abstract phonological information" and "specific acoustic information" (p. 531) about words that were encoded during study is a proposal that we understand to predict priming whether forced-choice alternatives are similar or dissimilar. In general, it appears that the data cannot be explained in any way that depends on the absolute value of some quantity involved in perceptual or decision processes (e.g., counts, activation, strength of a representation, or a new representation). Instead, the data require interactions among response alternatives. This can be seen most clearly by the difference between the counter model and the logogen model, the former with and the latter without interactions.

Morton's (1969, 1979) logogen model was designed to fit data from word-recognition studies with both auditory and visual presentation. The model has been successful in dealing with a wide range of phenomena in word identification. For the results reported in this article, bias due to prior presentation of a word in the naming-identification task and in the forced-choice task with similar alternatives could be modeled by lowering the threshold on the word's logogen as a function of prior study. However, the model would also predict a bias in forced choice for dissimilar alternatives because less evidence would be needed to reach the lowered threshold no matter whether the forced-choice alternative was similar or dissimilar. What would be needed is some way for the logogens to be assessed relative to each other. Morton (1970) ruled out this kind of decision rule partly because the data he considered did not require it. Ratcliff and McKoon's (in press) counter model can be seen as an implementation of a relative decision scheme within a logogen-like framework.

The counter model can explain bias in auditory word identification without recourse to multiple memory systems. Multiple memory systems are not needed because the counter model fits within a traditional information-processing framework. Some variables, such as auditory similarity, affect one part of processing (word identification), whereas other variables, such as type of semantic encoding, affect some other part of processing. In its framework, the counter model offers a detailed explanation of a number of the empirical phenomena found with word-identification paradigms and also explains how these findings relate to other paradigms. Whether implicit memory theories can provide an equally detailed account of word identification, complete with mechanisms and quantitative predictions, is a question that awaits further research.

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(Appendix follows on next page)

Appendix

Stimuli for Experiments 1, 2, and 3

Similar word	Similar word	Dissimilar word
sunk	sung	tire
hound	found	stuff
street	streak	branch
lint	flint	stretch
dealt	belt	cinch
meek	meat	fifth
stroke	strode	town
stove	dove	hitch
belong	along	neglect
slack	slab	main
stud	stuck	squeeze
ridge	bridge	blessed
glaze	blaze	porch
tooth	booth	by
sheet	sheep	gross
grace	brace	yet
thorough	furrow	communion
pinch	inch	spire
lamp	lamb	ice
dust	dusk	road
dome	comb	sing
cheek	cheap	stop
crest	breast	nerve
disc	bisque	conception
hire	fire	leaves
accuse	abuse	bench
taunt	gaunt	idle
live	cliff	want
tangle	angle	sumptuous
prior	dryer	virtue
death	deaf	trial
whip	whig	selves
does	buzz	least
loud	cloud	rest
place	lace	woods
love	glove	rich
haze	faze	roast
lime	climb	convenience
guise	dies	balloon
thumb	hum	weird
soap	soak	out
pause	cause	function
swept	sweat	endless
awake	await	none
thirst	first	gift
dash	cache	stream
grave	brave	wise
depart	apart	loathsome
stiff	skiff	mosaic
pump	bump	jazz
flux	floods	wash
accord	aboard	create
halt	fault	lunch
mike	might	flower
howl	foul	lodge
gloom	bloom	plasma
select	collect	retain
smith	myth	quest
tomb	boom	lunch

Note. Columns 1 and 2 are the similar word pairs from Experiments 1 and 2, and Columns 2 and 3 are the dissimilar word pairs from Experiment 3.

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