Journal of Experimental Psychology: General
2002, Vol. 131, No. 1, 38–47

0096-3445/02/$5.00 DOI: 10.1037//0096-3445.131.1.38

Priming in Implicit Memory Tasks: Prior Study Causes Enhanced Discriminability, Not Only Bias

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R. Ratcliff and G. McKoon (1995, 1996, 1997; R. Ratcliff, D. Allbritton, & G. McKoon, 1997) have argued that repetition priming effects are solely due to bias. They showed that prior study of the target resulted in a benefit in a later implicit memory task. However, prior study of a stimulus similar to the target resulted in a cost. The present study, using a 2-alternative forced-choice procedure, investigated the effect of prior study in an unbiased condition: Both alternatives were studied prior to their presentation in an implicit memory task. Contrary to a pure bias interpretation of priming, consistent evidence was obtained in 3 implicit memory tasks (word fragment completion, auditory word identification, and picture identification) that performance was better when both alternatives were studied than when neither alternative was studied. These results show that prior study results in enhanced discriminability, not only bias.

Over the years, researchers have identified a large number of variables that affect the processes involved in the identification of words and pictures. To give just one example, it has been consistently found that responses to words encountered frequently in natural language are faster and more accurate than responses to words encountered relatively infrequently in natural language. A question that has interested researchers for quite some time is whether effects such as the word frequency effect reflect a bias that favors one type of stimulus (e.g., high-frequency words) over the other (e.g., low-frequency words) or whether they reflect a true difference in the accuracy with which different types of stimuli are processed. Recently, the issue of bias and enhanced processing has attracted interest from researchers in the field of implicit memory (Masson & MacLeod, 1996; Ratcliff & McKoon, 1995, 1996, 1997). Ratcliff and McKoon have argued that repetition priming effects reflect bias and not enhanced processing of recently studied stimuli. The aim of the present study was to investigate whether repetition results only in a bias effect or whether there is also evidence for enhanced processing. The experiments were designed to separate the contributions of bias and enhanced processing to repetition priming. However, as we argue later in the General Discussion section, the approach taken here to disentangling the effects of bias and enhanced processing can also be applied to studying the effects on perceptual identification of variables other than prior study (e.g., word frequency and the emotional status of stimuli).

A large body of research has shown that prior exposure to a stimulus can affect the later processing of that stimulus, showing memory for the earlier presentation. For example, in an auditory word identification task, Church and Schacter (1994; Schacter & Church, 1992) have shown that earlier presentation of a word increases the probability of correctly identifying that word when it is later presented in white noise. Such long-term repetition priming effects can be demonstrated even though no reference is made to the study episode, when participants are not aware of any relation between the study episode and the task used at test, and even with amnesic patients who are unable to recall the earlier episode at all. Tasks used to study the effect of prior study on later performance without making reference to the study episode, such as the auditory word identification task, are called implicit memory tasks. Other implicit memory tasks that have been used to study priming are visual word identification (Bowers, 1999; Jacoby & Dallas, 1981; Masson & Freedman, 1990; Salasoo, Shiffrin, & Feustel, 1985), picture identification (Ratcliff & McKoon, 1996; Reinitz & Alexander, 1996), word stem completion (Graf, Squire, & Mandler, 1984), and word fragment completion (Roediger, Weldon, Stadler, & Riegler, 1992).

Many researchers assume, either explicitly or implicitly, that presentation of a stimulus enhances its future processing. For example, it is often said that the processing of a stimulus is facilitated by the prior presentation of that stimulus in the experiment. One proponent of the view that prior study increases the efficiency with which a word is encoded is Schacter (1994). Schacter argued that priming is mediated by a *perceptual representation system* (PRS). The PRS consists of three subsystems: the visual-word-form system, the auditory-word-form system, and the structural-description system. These subsystems supposedly handle different types of information. For example, the visual-word-form system is involved in word stem completion and visual word

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René Zeelenberg was supported by a grant from the Foundation for Behavioral and Social Sciences of the Netherlands Organization for Scientific Research. We thank Marissa Stoffers for her assistance in programming Experiments 2 and 3 and Bastiaan Kroeger for his assistance in preparing the stimuli of Experiment 3. We thank Rich Shiffrin for helpful discussions.

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identification, whereas the structural-description system is involved in object or picture recognition. Although the subsystems process different kinds of information, they are assumed to share common features and principles of operation. For example, the three subsystems support unconscious contributions to performance (i.e., implicit memory phenomena) and operate at a level that does not involve access to the meaning of words. The view that prior study of a stimulus enhances its subsequent processing is expressed particularly clearly in the following statement by Schacter (1994): "Visual priming may make it easier for the PRS mechanisms involved with visual word form representation to extract visual information from the test cue" (p. 237). According to this view, prior study results in a better perceptual encoding of the test stimulus and, thus, a true increase in performance. Similar arguments have been made by other researchers (e.g., Reinitz & Alexander, 1996; Salasoo et al., 1985; Squire, 1992).

Recently, Ratcliff and McKoon (1995, 1996, 1997; Ratcliff, Allbritton, & McKoon, 1997; Ratcliff, McKoon, & Verwoerd, 1989) provided an alternative interpretation of priming in implicit memory tasks. They argued that prior study of a stimulus results in *bias* and not enhanced processing (see Masson & MacLeod, 1996, for a similar view). One task used by Ratcliff and McKoon (1997) to support their claim is the forced-choice visual word identification task. In this task, a word (e.g., *lied*) is briefly flashed on a screen and subsequently masked. The mask is followed by two alternatives (e.g., *lied* and *died*), and the participant's task is to choose which one of the two alternatives was flashed. In several experiments, Ratcliff and McKoon found that prior study of the target (e.g., *lied*) increased target identification. However, prior study of a visually *similar* foil (e.g., *died*) decreased target identification (i.e., performance was worse when the foil was studied prior to being presented in the identification task than when neither alternative was studied).

Another important finding was that this pattern of costs and benefits was obtained only when the alternatives were visually similar (e.g., *lied* vs. *died*). For visually *dissimilar* alternatives (*lied* vs. *sofa*), prior study had no effect (but see Bowers, 1999; McKoon & Ratcliff, 2001). In other words, there was no increase in overall performance due to prior study. In a series of experiments, Ratcliff, McKoon, and colleagues have provided evidence that bias effects occur not only in visual word identification but also in a large variety of other implicit memory tasks, including auditory word identification (Ratcliff et al., 1997), object decision (Ratcliff & McKoon, 1995), word fragment completion (Ratcliff & McKoon, 1996), word stem completion (Ratcliff & McKoon, 1996), picture naming (Ratcliff & McKoon, 1996), and picture identification (Ratcliff & McKoon, 1996; Rouder, Ratcliff, & McKoon, 2000). These findings seriously challenge the view that prior study results in a better perceptual encoding of the stimulus.

To explain the bias effect of prior study in visual word identification, Ratcliff and McKoon (1997) developed a *counter model*. In their model, words are represented as counters. The counters accumulate counts (i.e., evidence) over time as a result of the visual processing of the stimulus. In a forced-choice task, a word is chosen if the total number of counts in its counter exceeds that of the other counter by a certain criterial amount (e.g., 10 counts). The counter model distinguishes three types of counts: diagnostic counts, nondiagnostic counts, and null counts. *Diagnostic* counts are counts that correspond to perceptual features that are features of the target and not of the foil (e.g., *l* in *lied* vs. *died*). Diagnostic counts discriminate between the target and the foil and are always taken by the counter of the target. *Nondiagnostic* counts are counts that correspond to features of both alternatives (e.g., *i* in *lied* vs. *died*). Diagnostic and nondiagnostic counts are both determined by the stimulus. In addition, there are also counts that are not determined by the stimulus. These so-called *null* counts represent random noise in the system. Nondiagnostic counts and null counts share the property that they do not discriminate between the target and the foil. If neither alternative is studied, nondiagnostic counts and null counts are randomly assigned to the two counters.

In the counter model, priming is assumed to affect the process by which counts are distributed: The counter of a studied alternative becomes an attractor that steals counts that would otherwise have been taken by the nonstudied alternative. To be more specific, prior study affects the probability with which nondiscriminative counts are assigned to the counters of either alternative. For a studied alternative, whether this is the target or the foil, the probability that a nondiagnostic or null count is taken by its counter increases slightly (e.g., from .50 to .51). This results in a benefit when the target word has been studied but in a cost when the foil has been studied. The lack of a bias effect for dissimilar alternatives (e.g., a choice between *lied* and *sofa*) is explained by assuming that counters are arranged or stored according to orthographic similarity. Because the attractive force of a studied word is rather weak, it can steal counts from nearby similar words but not from more distant dissimilar words.

An important characteristic of the counter model is that prior study of a word does not affect the probability of detecting a target diagnostic count when that word is flashed. Thus, prior study of a word supposedly does *not* enhance perceptual processing in the sense that more information is extracted from the stimulus to discriminate between the target and the foil. Neither is extraction of information from the stimulus assumed to be less error prone or less noisy as a result of prior study. In other words, the counter model does not assume that prior study leads to an overall improvement in performance. Rather, prior study results in a tendency to interpret ambiguous perceptual information in a way that is consistent with previous experience. This is an important characteristic of the counter model because it differs fundamentally from the assumption that is held by many researchers of repetition priming, namely the assumption that prior study of a stimulus improves the perceptual processing of that stimulus when it is presented on a later occasion.

A pure bias interpretation of repetition priming predicts that performance is not affected by study of *both* alternatives (relative to study of neither alternative) because it assumes that participants do not have more perceptual information available to discriminate between the target and the foil. Also, when both alternatives are studied, there is no reason why participants should have a preference to choose one alternative over the other. This notion is incorporated in the counter model by the assumption that the attractive forces cancel when both alternatives are studied. Ratcliff and McKoon (1997, Experiment 2) obtained the result predicted by a pure bias explanation of priming in implicit memory: Performance in the condition in which both alternatives had been studied was equivalent to that in the condition in which neither alternative had been studied. The same result was obtained in several experiments conducted by Masson and MacLeod (1996). These results seem to indicate that prior study does not result in an overall improvement in performance.

Recently, however, evidence has been obtained that questions the assumption that prior study results in only bias. These studies (Bowers, 1999; Wagenmakers, Zeelenberg, & Raaijmakers, 2000), like Experiment 2 of the Ratcliff and McKoon (1997) study, compared performance in conditions in which either both or neither of the alternatives had been studied previously. A critical difference between the Ratcliff and McKoon study and the Bowers and Wagenmakers et al. studies, however, is that the latter manipulated word frequency. Both Bowers and Wagenmakers et al. obtained evidence of enhanced discriminability for low-frequency words but not for high-frequency words. Thus, there is evidence that, at least in visual word identification, prior study may result in enhanced discriminability for low-frequency words.

As we noted earlier, Ratcliff, McKoon, and colleagues (Ratcliff et al., 1989, 1997; Ratcliff & McKoon, 1995, 1996) have shown that bias occurs in a large variety of implicit memory tasks. The recent findings of Bowers (1999) and Wagenmakers, Zeelenberg, and Raaijmakers (2000) in a visual word identification task raise the question of whether evidence for enhanced discriminability may also be obtained for stimuli presented in another modality, such as in auditory word identification or in tasks that do not rely on lexical processing (e.g., picture identification). The aim of the present study therefore was to investigate whether additional evidence for enhanced discriminability might be found in several of the implicit memory tasks in which Ratcliff and McKoon obtained bias effects.

The present study addressed the question of whether or not prior study results in enhanced discriminability in three different implicit memory tasks: word fragment completion, auditory word identification, and picture identification. Given that the recent effects of enhanced discriminability in visual word identification were generally quite small or even absent when high-frequency words were used, the present experiments were designed to maximize the chances of obtaining evidence of enhanced discriminability. In all experiments reported in this article, the stimuli were studied three times prior to their presentation in the test task. In addition, low-frequency words were used in Experiments 1 (word fragment completion) and 2 (auditory word identification).

It is important to note that previous claims that prior study results in enhanced processing have almost universally been based on tasks in which the effects of bias and enhanced discriminability could not be disentangled. With the exception of the studies of Bowers (1999) and Wagenmakers, Zeelenberg, and Raaijmakers (2000), studies have mostly relied on tasks such as a free response perceptual identification task (sometimes called naming) in which a word is briefly presented and subsequently masked. In this task, participants have to say the word they think was presented (i.e., they do not choose from alternatives). As demonstrated by Ratcliff and McKoon (1997), priming in free response perceptual identification can be explained without assuming enhanced processing (i.e., priming can be accounted for by assuming that a studied word steals counts from unstudied similar words). In fact, given that enhanced discriminability effects are quite small in general and virtually absent for high-frequency words (e.g., Wagenmakers, Zeelenberg, & Raaijmakers, 2000), it seems that the priming effects obtained in previous studies with free response procedures were largely due to bias. Thus, claims for enhanced processing of repeated stimuli based on an increase in performance in a free response identification task are unwarranted.

A forced-choice procedure was used in all experiments of the present study to disentangle the effects of bias and enhanced discriminability. Enhanced discriminability was assessed by comparing performance in a condition in which both alternatives were studied with performance in a condition in which neither alternative was studied. As explained earlier, a pure bias explanation of repetition priming does not predict a difference between the study-both and study-neither conditions. However, if prior study results in enhanced processing, performance is expected to be better in the study-both condition than in the study-neither condition. Therefore, such a finding would provide evidence against a pure bias interpretation of repetition priming.

The finding of an enhanced discriminability effect has implications for the way in which the presence of bias should be assessed. In previous studies (e.g., Ratcliff & McKoon, 1997; Wagenmakers, Zeelenberg, & Raaijmakers, 2000), bias was calculated by taking the difference between the study-target condition and the study-foil condition. If, however, we found a difference between the study-both condition and the study-neither condition, the difference between the study-target condition and the study-foil condition would not only reflect bias. Instead, this measure of bias would be contaminated by an enhanced discriminability effect, because it would be affected not only by a bias to choose a studied alternative over a nonstudied alternative but also by a difference in the efficiency of processing the target stimulus. Therefore, the following four study conditions were present in Experiment 1 and Experiment 2: (a) Only the target was studied, (b) both the target and the foil were studied, (c) neither the target nor the foil was studied, and (d) only the foil was studied. Because of the limited number of available stimuli, Experiment 3 included only the second condition (both alternatives studied) and the third condition (neither alternative studied). Bias was calculated in Experiments 1 and 2 by taking the sum of the following two differences: (a) the difference in performance between the study-target condition and the study-both condition and (b) the difference in performance between the study-neither condition and the study-foil condition. Both differences reflect a bias to choose a studied alternative over a nonstudied alternative and are not contaminated by a difference in the efficiency of processing the target stimulus (i.e., both differences are based on comparisons between conditions that do not differ in the study status of the target). The general implications and advantages of our procedure to disentangle the effects of bias and enhanced discriminability are elaborated on in the General Discussion section.

Experiment 1: Word Fragment Completion

Ratcliff and McKoon (1996) showed that, in a word fragment completion task, prior study results in bias. They used a yes–no task in which a test word was presented and the participant's task was to decide whether the test word was a correct completion of the word fragment. Ratcliff and McKoon used an 800-ms deadline for responding to prevent participants from checking the test word letter by letter with the word fragment. They found that participants were more likely to accept the correct completion (e.g., *tramway*) of the word fragment (e.g., __*r*__*mw*____) if they had previously studied this "target" word than if they had not studied it. However, they were less likely to accept the correct completion if they had studied an orthographically similar "foil" (e.g., *framework,* sharing several letters with the word fragment but not being a correct completion of the word fragment). Likewise, participants were more likely to (incorrectly) accept the similar foil if they had previously studied the similar foil but less likely to accept the similar foil if they had studied the target. In other words, participants were more likely to accept a word as a correct completion of the word fragment when they had previously studied that word, irrespective of whether the studied word actually was the correct completion of the word fragment.

Although bias effects can be obtained in word fragment completion and other implicit memory tasks such as visual word identification, the processes underlying priming in word fragment completion probably differ in several important aspects from those underlying priming in word identification (Masson & MacLeod, 1996; Tenpenny, 1995; Witherspoon & Moscovitch, 1989). The present experiment therefore examined whether the recent evidence obtained in masked visual word identification showing enhanced discriminability as a result of prior study can also be obtained in word fragment completion. In this experiment, a two-alternative forced-choice paradigm was used. The procedure closely followed the one used by Ratcliff and McKoon (1996). The word fragment was presented for 4 s. Subsequently, two words were presented side by side, and the participant had to choose which of the two alternatives was the correct completion of the word fragment. Participants had to respond within 1,400 ms of the presentation of the alternatives.[1] The experiment consisted of the four study conditions described earlier (only target studied, both target and foil studied, neither target nor foil studied, and only foil studied). If prior study results in enhanced discriminability, performance should be better when both alternatives have been studied than when neither alternative has been studied.

Method

Participants. Fifty-two students at the University of Amsterdam participated for course credit. All participants were native speakers of Dutch.

Materials. The stimuli consisted of 96 word pairs (e.g., *tramway–framework*) ranging in length from 7 to 11 letters.[2] The words ranged in frequency from 1 per million to 5 per million (mean frequency: 1.6 per million). Frequency counts were obtained from the CELEX (Centre for Lexical Information) norms (Baayen, Piepenbrock, & van Rijn, 1993). All stimuli were common Dutch words. Each pair had one corresponding word fragment (e.g., __*r*__*mw*____). Only one of the two words, the target (e.g., *tramway*), was the correct completion of the word fragment. The other word, the foil (e.g., *framework*), shared letters with the fragment but was not a correct completion.

Design. Experimental stimuli in the study-target, study-both, study-neither, and study-foil conditions were presented in four study–test blocks. The study phase of each study–test block consisted of 24 words presented three times each, in a different random order for each participant. Immediately after the study phase, there was a test phase consisting of 24 test trials. Each study–test block of 24 trials consisted of 6 test trials for each of the four conditions. Thus, during study, the following stimuli were presented: 6 words that were later presented as targets in the study-target condition, 6 words that were later presented as targets in the study-both condition, 6 words that were later presented as foils in the study-both condition, and 6 words that were later presented as foils in the study-foil condition. Of course, no words were studied in the study-neither condition. In the test phase, word fragments were presented in a two-alternative forced-choice task.

A counterbalanced design was used to create four stimulus lists. Each list contained the same word pairs, but the study condition for each word pair was dependent on the list. Thus, for any given participant, each pair of alternatives appeared in only one condition. Across the four lists, each pair of alternatives was rotated once through the four different study conditions.

Procedure. The experiment began with four practice trials. The practice trials were given to familiarize the participants with the fragment completion task (hence, there were no study trials during practice). After the practice trials, the four study–test blocks were presented. On each study trial, a word was presented on the computer screen for 3 s. Participants were instructed to study the words for a later (unspecified) memory test that would be administered at the end of the experiment. They were informed that some of the words presented in the fragment completion task were words they had studied previously but that there was no relation between study status and the correct answer.

A test trial started with the presentation of the word fragment for 4 s. Next, the word fragment was replaced by two alternatives that were presented side by side on the computer screen. Participants had to press the *z* key with their left index finger if they thought the left-hand word was the correct completion of the word fragment or the *?/* key with their right index finger if they thought the right-hand word was the correct completion of the word fragment. The location (left or right) of the correct alternative was determined randomly. A 1,400-ms deadline was used to prevent participants from attaining perfect performance. If participants failed to make a response within 1,400 ms, the message "langzaam" (Dutch for *slow*) was presented for 1 s. If the response was incorrect, the message "fout" (Dutch for *error*) was presented for 1 s.

Results and Discussion

On 5.5% of the trials, participants failed to respond within the 1,400-ms deadline. The number of responses slower than 1,400 ms did not vary as a function of study condition, $F(3, 153) = 1.00$, $p > .25$, $MSE = 1.458$. Figure 1 presents the percentage of correct fragment completions as a function of study condition. Analysis of variance (ANOVA) showed a significant effect of study condition, $F(3, 153) = 9.00$, $p < .0001$, $MSE = 5.492$. Of particular interest was the difference between the study-both condition and the study-neither condition. The planned comparison was significant, $F(1, 153) = 4.55$, $p < .05$, $MSE = 5.492$, indicating that performance was better when both alternatives had been studied previously than when neither alternative had been studied. As we explained in the introduction, the finding of enhanced discriminability has consequences for the way in which a measure of bias should be obtained. As described earlier, bias was calculated by taking the sum of two differences: (a) the difference in performance between the study-target condition and the study-both condition and (b) the difference

[1] Ratcliff and McKoon (1996) used a deadline of 800 ms to discourage participants from comparing the test word letter by letter with the word fragment. Note, however, that their experiment involved a yes–no task in which only one test word was presented. A two-alternative forced-choice paradigm was used in our experiment, which required participants to read two test words instead of one. We therefore used a deadline of 1,400 ms.

[2] Examples are presented in English, but the actual stimuli consisted of Dutch words.

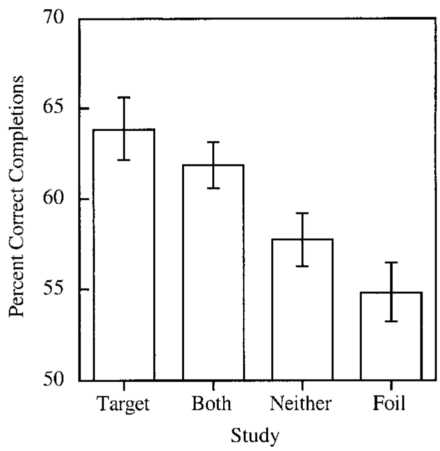

Figure 1. Percentages of correct completions (with standard error bars) in forced-choice word fragment completion as a function of study condition: Experiment 1.

in performance between the study-neither condition and the study-foil condition. A *t* test showed that the bias effect was significant, $t(51) = 2.59$, $p < .05$. To our knowledge, this is the first experiment to use a forced-choice paradigm to obtain separate estimates of bias and enhanced discriminability by comparing the appropriate conditions.

The most important result of the present experiment is that performance was better in the study-both condition than in the study-neither condition. This result is consistent with the hypothesis that prior study results in enhanced discriminability and shows that priming in word fragment completion is not due simply to a bias to prefer a studied item to a similar nonstudied item. Thus, the present findings extend the evidence recently obtained in visual word identification (Bowers, 1999; Wagenmakers, Zeelenberg, & Raaijmakers, 2000) to word fragment completion, an implicit memory task often used to study repetition priming.

Experiment 2: Auditory Word Identification

In Experiment 2, we studied the effect of prior study on auditory word identification using the two-alternative forced-choice paradigm. Test words were presented in white noise. Subsequently, participants had to choose which of two alternatives was the presented word. Using this task, Ratcliff et al. (1997) showed that prior study results in bias. The aim of the present experiment was to investigate whether prior study causes only bias or whether it also causes enhanced discriminability.

Method

Participants. Sixty-four students at the University of Amsterdam participated for course credit. All participants were native speakers of Dutch.

Materials and apparatus. The stimuli consisted of 96 similar-sounding word pairs (i.e., words differing in pronunciation by only one phoneme). Frequency counts were obtained from the CELEX norms (Baayen et al., 1993). The frequency of the words ranged from 1 per million to 30 per million (mean frequency: 2.9 per million). The stimulus words were, thus, of relatively low frequency. Within each pair, one word was randomly designated the target.

The words were spoken by a female speaker and digitally recorded on a computer with a sampling rate of 44100 Hz. Test items (but not study items) were mixed with white noise. The relative amplitude of white noise was adjusted for each test word separately to a level at which the experimenters judged that identification rates for each word would be neither at floor nor at ceiling. A pilot study was conducted to adjust the relative amplitude of white noise for test words that showed performance close to floor or ceiling. Stimulus presentation and data collection were controlled by an Apple Macintosh Power PC. Study and test stimuli were presented over a Sennheiser HD 495 headphone.

Design and procedure. The design was largely identical to that of Experiment 1. The experimental stimuli were presented in four study–test blocks. The study phase of each study–test block consisted of 24 words that were presented three times each. A test phase followed each study phase and consisted of 24 test trials. In the test phase, words masked with white noise were presented in a two-alternative forced-choice task. The experiment consisted of four conditions: study target, study both, study neither, and study foil. In both the study and test phases, stimuli were presented in a random order. A counterbalanced design was used to create four stimulus lists.

Our procedure closely followed the one used by Ratcliff et al. (1997). During the study phase, participants rated how clearly each word was pronounced using a scale ranging from 1 to 5. Participants entered their ratings by clicking a number on the screen using the mouse. The next word was presented 1 s after the participants clicked a number. The beginning of each study block and test block was signaled by the message “press a key to continue.”

In the test phase, words masked with white noise were presented in a two-alternative forced-choice task. Each test trial started with the presentation of the test word over the headphones. The duration of the white noise masking the test word was 3 s, with at least 1 s of noise before the onset of the test word and 1 s of noise after the offset of the test word. Immediately following the end of the presentation of the test word, two alternatives were presented side by side near the center of the computer screen. Responses were collected with an external button box. Participants pressed the left key with their left index finger if they thought the left-hand word was the auditory presented test word and the right key with their right index finger if they thought the right-hand word was the auditory presented test word. The location (left or right) of the correct alternative was determined randomly. Because in masked perceptual identification performance is limited primarily by the degraded presentation of the stimulus, no response deadline was imposed. To make the procedure as similar as possible to that of Ratcliff et al. (1997), we provided no feedback. There was a 1-s interval between the response of the participant and the start of the next trial. Five practice trials were included at the beginning of the experiment to familiarize participants with the auditory word identification task.

Results and Discussion

Percentages of correctly identified targets as a function of study condition are shown in Figure 2. The ANOVA showed a significant effect of study condition, $F(3, 189) = 44.11$, $p < .0001$, $MSE = 5.517$. A planned comparison analysis was performed to test the difference between the study-both condition and the study-neither condition. The difference was significant, $F(1, 189) = 5.27$, $p < .05$, $MSE = 5.517$, indicating that performance was better when both alternatives had been studied previously than when neither alternative had been studied. These results extend the findings of Wagenmakers, Zeelenberg, and Raaijmakers (2000) to

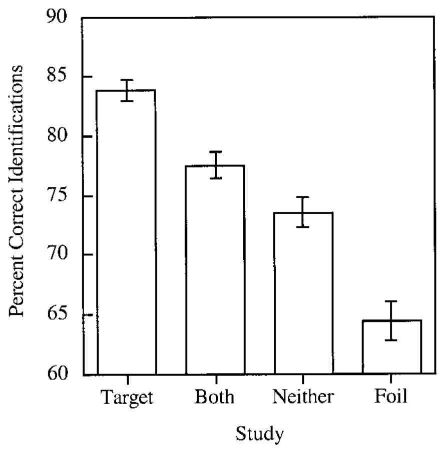

Figure 2. Percentages of correct identifications (with standard error bars) in forced-choice auditory word identification as a function of study condition: Experiment 2.

the auditory modality. As in Experiment 1, bias was calculated by adding the difference between the study-target and study-both conditions to the difference between the study-neither and study-foil conditions. A t test showed that the bias effect was again significant, $t(63) = 8.98$, $p < .0001$.

Experiment 3: Picture Identification

In Experiment 3, we used another implicit memory task, picture identification, to extend and corroborate the basic findings of Experiments 1 and 2 that prior study leads to enhanced discriminability. Ratcliff and McKoon (1996; Rouder et al., 2000) used a forced-choice picture identification task to show that prior study results in bias. The aim of the present study was to investigate whether evidence for enhanced discriminability could also be obtained in picture identification, a task that does not rely on lexical processing. Such an effect would be consistent with ideas expressed by Reinitz and Alexander (1996), who studied repetition priming in picture identification and argued that "prior exposure to a stimulus results in an increased visual information-acquisition rate when it is subsequently encountered" (p. 129).

Method

Participants. Seventy-four students at the University of Amsterdam participated for course credit or a small monetary reward. The data of 6 participants performing below chance levels were discarded and replaced with the data of new participants; care was taken that the design of the experiment remained completely counterbalanced across participants.

Materials and apparatus. The stimuli consisted of 42 similar-looking pairs of pictures (i.e., black on white drawings; see Figure 3 for an example). Within each pair, one picture was randomly designated the target and the other picture the foil. A mask was used to make identification of the pictures more difficult. The mask completely covered the area where the picture was presented and consisted of an aggregation of lines taken from a number of different pictures of the stimulus set. Stimulus presentation and data collection were controlled by an Apple Macintosh Power PC.

Design and procedure. The experiment consisted of one study block that was followed by a test block. The study block consisted of 42 pictures presented three times each for 2 s. There was a 200-ms interval between the presentations of the pictures. Participants were instructed to study the pictures for a later (unspecified) memory test. The test block followed the study block and consisted of 42 test trials. There were two conditions: study both and study neither. Because of the limited number of available pictures, the study-target and study-foil conditions of Experiments 1 and 2 were not included in the design of the present experiment.

Experiment 3 involved a procedure very similar to the one used by Ratcliff and McKoon (1996, Experiment 2). Each test trial started with the presentation of a row of plus signs for 700 ms. The plus signs were followed by the picture that was flashed for 40 ms. A pattern mask immediately followed the picture and was presented for 400 ms. Next, two pictures were presented side by side until the participant responded. Participants had to press the *z* key with their left index finger if they thought the left-hand picture was the briefly flashed test picture or the *?/* key with their right index finger if they thought the right-hand picture was the briefly flashed test picture. The location (left or right) of the correct alternative was determined randomly. As in Experiment 2, no response deadline was imposed, and no feedback was provided. There was a 300-ms interval between the response of the participant and the start of the next trial. In both the study and test phases, stimuli were presented in a different random order for each participant. Five practice trials were included at the beginning of the experiment to familiarize the participants with the picture identification task.

Results and Discussion

Mean percentage of correctly identified pictures was calculated for each participant. When neither the target nor the foil had been studied, 71.5% of the pictures were correctly identified. When both the target and the foil had been studied, 74.7% of the pictures were correctly identified. The difference between the study-both and study-neither conditions was significant, $t(73) = 2.19$, $p < .05$. Thus, in a forced-choice picture identification task, prior study of both alternatives again resulted in increased performance relative to study of neither alternative. This result is problematic for a pure bias account of repetition priming and shows that prior study results in enhanced discriminability in a task that does not rely on lexical processing.

General Discussion

In the present study, we investigated whether prior study of a stimulus resulted in only bias or also enhanced discriminability. Using a forced-choice procedure, we found that in three implicit memory tasks, word fragment completion, auditory word identification, and picture identification, performance was consistently better when both alternatives had been studied previously than when neither alternative had been studied. In a recent study, we also found evidence for enhanced discriminability in visual word

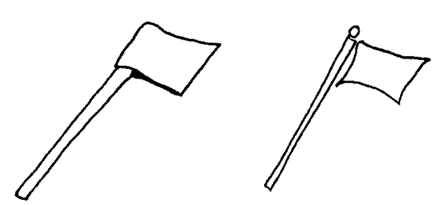

Figure 3. Example pair of similar pictures used in Experiment 3.

identification (Wagenmakers, Zeelenberg, & Raaijmakers, 2000). These findings contradict the claim of Ratcliff and McKoon (1996, 1997; Ratcliff et al., 1989, 1997) that priming is solely due to bias. This claim was based on their finding that, in a variety of tasks involving a forced-choice paradigm, prior study resulted in a benefit when the target had been studied but in a cost (of about equal size) when the foil had been studied. Moreover, in one experiment, Ratcliff and McKoon (1997, Experiment 2) found no effect when both alternatives had been studied. However, as we explained in the introduction, Ratcliff and McKoon may have failed to find evidence for enhanced discriminability because they did not select their stimulus materials to be low-frequency words and because a limited amount of study was given to each stimulus. In the present study, we obtained clear evidence for enhanced discriminability by using low-frequency materials and presenting stimuli on multiple study trials. In the following, we first discuss the implications of the present results for theories of implicit memory. We then discuss the broader implications of the present study by showing how the procedures we used to disentangle the effects of bias and enhanced discriminability can be applied to study the effects of other variables known to influence word and picture recognition.

Implications for Theories of Implicit Memory

The present results are consistent with the view that prior study enhances perceptual processing. Such a view has been proposed by Schacter (1994). He argued that priming reflects the operations of a PRS. In this account, multiple memory systems underlie priming in different tasks. For example, priming in picture identification is supposedly mediated by a structural-description system. According to Schacter, prior study of a stimulus affects the processing of that stimulus on a later occasion through facilitation of the feature extraction process. The hypothesis that prior study leads to increased feature extraction for repeated stimuli is consistent with the present findings, namely better performance in a forced-choice identification task when both alternatives have been studied than when neither alternative has been studied.

Although the finding of an enhanced discriminability effect in the present study is consistent with the proposals of Schacter (1994), there are several other findings that must be accounted for. The first one is the mere finding of bias itself. As we just mentioned, the theory of Schacter attributes priming to the facilitation of feature extraction. Such a mechanism does not, however, result in a bias effect. Thus, the theory of Schacter should be extended to include a mechanism that results in a bias for recently studied items. The second finding that should be accounted for is that bias is obtained for similar pairs but not for dissimilar pairs. The third important finding is that bias is obtained even when flash time is so short that participants perform at chance and that bias decreases slightly as flash time increases. Together, these findings place important constraints on theories of implicit memory.

One could argue that bias effects are due to explicit-retrieval strategies and that, therefore, bias should not be accounted for by theories of implicit memory. However, some findings suggest that such explicit-retrieval strategies are not, in general, responsible for bias effects. First, an explanation that attributes bias to explicit-retrieval strategies does not explain why bias is obtained for similar but not for dissimilar alternatives. Second, Masson (2000) recently showed that bias is affected by a study-to-test change in modality, whereas episodic recognition is not affected by such a change. Thus, it seems that bias effects reflect implicit memory processes instead of explicit-retrieval strategies. As a result, the challenge for theories such as that of Schacter is to provide a detailed explanation of bias effects.

Let us return to our main finding, that prior study of both alternatives consistently resulted in better performance than prior study of neither alternative. Our findings show that the assumption of the counter model that prior study does not result in enhanced discriminability is too strong. Nonetheless, we would like to mention that the counter model successfully accounted for a wide range of data available at the time the model was conceived. Ratcliff and McKoon (1997) were among the first to develop a quantitative model of priming in implicit memory and to point out that repetition priming effects in implicit memory tasks do not necessarily indicate more efficient processing for repeated stimuli, as is often assumed. Instead, to a considerable extent, priming effects in implicit memory seem to reflect a bias to perceive a stimulus that was previously studied, irrespective of whether or not this is the actual target stimulus. We would like to stress that we do not contest that prior study causes bias. However, we do contest that prior study causes only bias. The findings of the present study clearly show that, in a wide range of implicit memory tasks, prior study results in enhanced discriminability.

This point has been recognized recently by Ratcliff and McKoon (2000). To account for our data (Wagenmakers, Zeelenberg, & Raaijmakers, 2000), they have modified their model. The new version of the counter model assumes that, for low-frequency words, prior study results in an increase in the probability of perceiving diagnostic features. Such an increase results in better performance when both alternatives have been studied than when neither alternative has been studied. Therefore, the present data can be accounted for by the latest modified version of the counter model.

Although the present results are consistent with the notion that more information is extracted from the impoverished stimulus per unit time, we would like to point out that this is not the only possible explanation. As has been noted by some other researchers (Masson & McLeod, 1996), enhanced discriminability is a necessary but not sufficient condition for concluding that there are changes in lower level perceptual information processing. A possible account of enhanced discriminability without assuming an enhanced rate of feature extraction for previously studied stimuli is provided by the REM (retrieving effectively from memory) model for priming in perceptual identification (for details, see Schooler, Shiffrin, & Raaijmakers, 2001; see also Wagenmakers, Zeelenberg, Schooler, & Raaijmakers, 2000). Although the models differ in the way in which they account for enhanced discriminability, they all incorporate some mechanism that causes repeated stimuli to be processed more efficiently than new stimuli.

Disentangling Bias and Discriminability: General Implications

To the best of our knowledge, the present study is the first one to use a forced-choice paradigm to obtain separate estimates of the effects of bias and enhanced discriminability by including all conditions necessary to disentangle both effects. The experiments reported here focused on the issue of enhanced discriminability and its relevance to theories of implicit memory. We now discuss the extension of our paradigm to the effects of variables other than prior study on word recognition (e.g., word frequency). We would like to emphasize, though, that our paradigm could be applied equally well in other domains such as picture recognition and face recognition. Because it is often argued that a certain variable enhances the processing of a stimulus, it is necessary to design experiments in such a way that these claims can be tested. However, studies rarely include the appropriate conditions to support claims of enhanced processing. In the following, we first discuss how our approach to separating the effects of bias and discriminability might be applied to investigating the effects of variables other than prior study. We then present some examples showing that a failure to include the appropriate experimental conditions can lead to incorrect conclusions.

In general, the effects of bias and discriminability can be disentangled by using a forced-choice perceptual identification task. The principle is that, to assess whether a certain variable results in bias, one should compare two conditions for which the target stimuli do not differ on that variable. However, within conditions, there should be a difference on that variable between the target and foil alternatives. Thus, in assessing a word frequency bias, to give just one example, one could compare a condition with a high-frequency target and a low-frequency foil (we refer to this condition as the high-frequency–low-frequency [HF–LF] condition; the first member of the pair denotes the frequency of the target, and the second member denotes the frequency of the foil) and a condition with a high-frequency target and a high-frequency foil (the HF–HF condition). The important point is that the HF–LF condition and the HF–HF condition are equal with respect to the frequency of the target so that a possible difference between these two conditions is not affected by a difference in the efficiency of processing the target stimulus. Instead, a difference between these two conditions is due to a preferential bias to choose a high-frequency alternative over a low-frequency alternative. Likewise, bias can be estimated by comparing the LF–LF condition with the LF–HF condition. A total bias score can be obtained by taking the sum of both differences (i.e., the difference between the HF–LF condition and the HF–HF condition and the difference between the LF–LF condition and the LF–HF condition).

To assess whether a certain variable affects discriminability, the general principle is that one should compare two conditions for which the targets differ on that variable. However, within the two conditions, there should be no difference on that variable between the target and foil alternatives. Thus, to determine whether word frequency affects discriminability, one should compare the HF–HF condition with the LF–LF condition. Within the two conditions, there is no difference in word frequency between the target and the foil alternative. Hence, a bias to prefer a certain alternative based on a difference in word frequency should not affect the results. Instead, a difference between the two conditions is due to a difference in the efficiency of processing target stimuli of high and low frequency. Figure 4 presents hypothetical data and illustrates how estimates of bias and enhanced discriminability can be obtained by comparing the appropriate conditions.

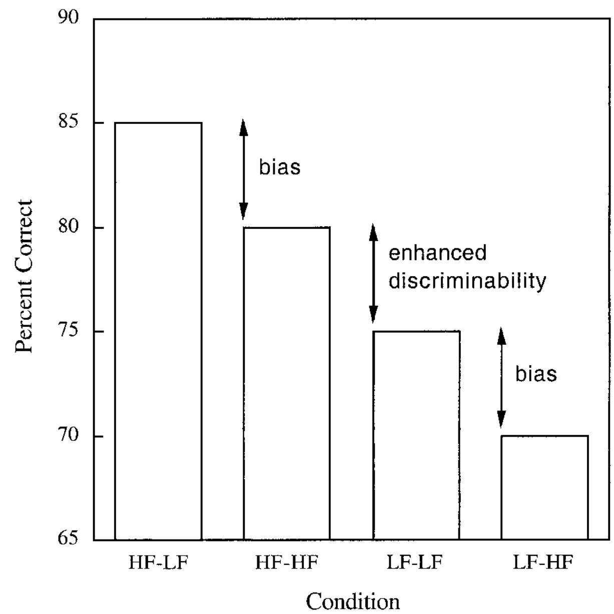

Figure 4. Hypothetical data showing percentages of correct target identifications as a function of both the frequency of the target and the frequency of the foil. In the example, word frequency causes both enhanced discriminability and bias. The difference between the HF–HF condition and the LF–LF condition reflects better discriminability for HF words than for LF words. Both the difference between the HF–LF and HF–HF conditions and the difference between the LF–LF and LF–HF conditions reflect a bias to choose an HF alternative. See text for details. HF = high frequency; LF = low frequency.

To recapitulate, the following four conditions are needed to disentangle the effects of word frequency on bias and discriminability: (a) HF–LF, (b) HF–HF, (c) LF–LF, and (d) LF–HF. Note the conceptual similarity of these conditions and the four conditions used in the present study: study target, study both, study neither, and study foil. Studies rarely include all four conditions that are necessary to obtain estimates of the effect of a certain variable on bias and discriminability. In fact, we are aware of only one other study that included all of these conditions (Wagenmakers, Zeelenberg, & Raaijmakers, 2000). Of course, it is not always necessary to include all four conditions. For example, if one is interested only in whether or not a variable affects discriminability, it is sufficient to include the HF–HF and LF–LF conditions. However, even these two conditions are rarely included in experimental designs.

Next, we present two examples that show how failure to include the necessary conditions can lead to incorrect conclusions. The first example is directly related to the present study. However, the same principle applies mutatis mutandis to other variables that affect perceptual identification. In some studies, enhanced discriminability is assessed by combining performance in the study-target and study-foil conditions and comparing it with performance in the study-neither condition. The rationale is that if prior study results in a true increase in performance (over and above bias), performance should be better in the combined condition than in the study-neither condition. If, however, prior study results in only bias, the increase in performance in the study-target condition and the decrease in performance in the study-foil condition should cancel. The problem associated with assessing enhanced discriminability in the way just described is that it presupposes that the scale of measurement is linear. To show that this concern is not purely hypothetical, we reanalyzed our data. In this analysis, we combined performance in the study-target and study-foil conditions and compared it with performance in the study-neither condition.[3] In both Experiment 1 and Experiment 2, the difference failed to reach significance (both ps $> .10$). Thus, if we had not included the study-both condition in our experiments, we would have falsely concluded that prior study does not result in enhanced discriminability.

A second example from the literature serves to further underline our point that the design of studies involving the two-alternative forced-choice paradigm has far-reaching implications. It is often argued that the emotional status of a word affects its processing. Researchers have been aware of the fact that such influences may be due to bias and have tried to control for these biases. To give an example, Kitayama (1990) compared performance for neutral and affective words in a two-alternative forced-choice perceptual identification task in an attempt to control for response bias. As is clear by now, a design with the following four conditions would be needed to disentangle the effects of bias and enhanced processing: (a) target neutral, foil affective; (b) target neutral, foil neutral; (c) target affective, foil affective; and (d) target affective, foil neutral. If accuracy in perception is truly different for neutral words and affective words, then there should be a difference between the second and third conditions. Differences between the first and second conditions and differences between the third and fourth conditions reflect bias. Kitayama (1990), however, compared performance between the first condition and the fourth condition. The problem with this comparison is that it is affected not only by a difference in the processing efficiency of the target stimulus but also by a possible bias to prefer one type of alternative over the other. Thus, the influence of bias and that of enhanced processing are confounded. The design of Kitayama (1990) was actually somewhat more complicated than just described because it also manipulated word frequency and "expectation." However, this is not problematic because the basic design mentioned could be expanded to include these variables.[4]

To show how the design used by Kitayama (1990) can lead to unwarranted conclusions, consider the following. Kitayama manipulated "expectation" because this was, according to Kitayama, a variable that could be responsible for some seemingly inconsistent results obtained in earlier work. Expectation was manipulated by showing the alternatives before the brief presentation of the target word (expectation present) or not doing so (expectation absent). Of course, participants were not informed which of the two alternatives would be briefly presented, but it was hypothesized that the "expectation" manipulation would affect the difference between the affective target and the neutral target conditions. This was indeed the case. The results showed a higher percentage of correct identifications for the affective target condition than for the neutral target condition when an expectation was present but no difference when expectation was absent. More precisely, for the affective condition, performance was better in the "expectation present" condition than in the "expectation absent" condition. For the neutral condition, in contrast, performance was worse in the expectation present condition than in the expectation absent condition. Kitayama discussed these results in terms of perceptual enhancement. However, the pattern of results closely resembles one of bias, because the presence of an expectation had both costs and benefits. Unfortunately, the design of the experiment does not allow one to make statements about the efficiency with which stimuli were encoded. If a condition in which both alternatives were neutral and a condition in which both alternatives were affective had been included, we could have assessed whether expectation truly enhances the processing of affective words under expectation present conditions.[5]

To summarize, the method used in the present study to disentangle the effects of bias and discriminability can be applied in other fields studying perceptual identification and may help in better understanding the mechanisms underlying performance. As we have shown, failure to include the appropriate conditions may lead to incorrect conclusions.

Summary and Conclusion

Several studies have suggested that the effects of prior study in various implicit memory tasks are entirely due to bias. In the present study, we consistently obtained evidence that prior study not only results in bias but also leads to enhanced discriminability. These results were obtained in three implicit memory tasks, word fragment completion, auditory word identification, and picture identification, with a forced-choice paradigm in which either both alternatives were studied or neither of the alternatives was studied. As predicted by an enhanced processing view of repetition priming, performance was better in the condition in which both alternatives were studied than in the condition in which neither alternative was studied.

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[3] We would like to note that this analysis is identical to an analysis that compares the difference between the study-target and study-neither conditions with the difference between the study-neither and study-foil conditions. Again assuming a linear scale of measurement, the rationale is that the former difference reflects both a bias effect and an enhanced discriminability effect, whereas the latter difference reflects only a bias effect, and hence an estimate of enhanced discriminability can be obtained by comparing both differences (i.e., if there is an enhanced discriminability effect, the former difference should be larger than the latter difference).

[4] We should add that Kitayama tried to estimate bias by adding a condition in which no stimulus was flashed. In this condition, only bias effects can be present, because there is no valid perceptual information by which the two alternatives can be discriminated. However, this method presupposes that the size of the bias effect does not change with flash time.

[5] In a later study, Kitayama (1991; see also Bootzin & Natsoulas, 1965) did compare both-alternatives-neutral and both-alternatives-affective conditions. However, the target-neutral, foil-affective condition and the target-affective, foil-neutral condition were now missing from the design, precluding the estimation of a bias effect. Moreover, expectation was not manipulated in this study, so nothing can be said about its influence on the efficiency with which stimuli are processed.

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Received February 28, 2000
Revision received July 12, 2000
Accepted July 28, 2001 ■