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The loss of repetition priming and automaticity over time as a function of degree of initial learning

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Two experiments were performed to investigate the buildup of repetition priming in a lexical decision task with repeated presentations and its decline over the course of 2 months. Priming was found to accumulate as a power function of presentations and to decline as a power function of time. Accuracy measures indicated that the loss rate of priming was unaffected by the amount of initial priming. Response time measures indicated the same result when the experiments were analyzed separately; however, when the data were combined, increased initial priming was associated with greater losses in priming over time. The data were interpreted in terms of automaticity, and the power function decline in priming was taken as support for memory-based models of automaticity. Possible ways to incorporate forgetting into memory-based theories of automaticity are discussed.

Repetition priming is the benefit accrued to the processing of a unit of information as a result of its having been encountered previously, with the benefit usually measured in terms of faster response time or greater accuracy. Duration is a fundamental aspect of the phenomenon. In the case of repetition priming in lexical decision tasks, for example, the recognition of a letter string as a word implies that the word has been seen in the past. For the concept of repetition priming to have any meaning, priming must be temporary. Understanding the transitory nature of this repetition effect is central to the understanding of repetition priming.

Sloman, Hayman, Ohta, Law, and Tulving (1988) reviewed several studies on the duration of repetition priming over relatively short intervals and then conducted a series of experiments in which they measured priming shortly after study and 1 week after study. These experiments consistently indicated that the repetition effect declined quickly in the first few minutes after training, and that there was relatively little further loss between a few minutes and a week after training.

Salasoo, Shiffrin, and Feustel (1985) used a different technique, extended practice, to look at priming over a longer interval. In a series of word identification experiments, they found that repetition priming could still be detected 1 year after training. They also found that repetition priming was cumulative; identification thresholds decreased continuously over 30 presentations.

These two studies suggest further questions. Although Salasoo et al. (1985) showed that priming increased with increased numbers of repetitions and that the priming could be retained for a year, they did not explore the loss of priming as a function of the number of repetitions. After examining performance at two retention intervals, Sloman et al. (1988) concluded that the loss of priming slowed after the first few minutes following training. They compared the change in priming from immediately after training to a few minutes later with the change in priming from a few minutes after training to a week later. The course of priming after a week was not charted.

In the present pair of experiments, we attempted to replicate, merge, and extend the findings of Salasoo et al. (1985) and Sloman et al. (1988) by training subjects on a lexical decision task and then retesting them after various retention intervals. In the first experiment, items were repeated up to 16 times and retested 5 min, 8 h, 1 day, or 1 week later. The second experiment was similar, but the retention intervals were 1 and 2 months long.

The growth of the repetition priming was checked by observing the effect of presenting items up to 16 times. Furthermore, by presenting different items different numbers of times, the effect of the number of presentations on the loss of priming could be observed.

Taken together, the present two studies offered an opportunity to follow the decline in repetition priming over a longer interval than those summarized by Sloman et al. (1988). By measuring priming over a greater length of time, including two points more than a week following training, the present research provided the opportunity to add more data points to verify Sloman et al.'s conclusion that the loss of priming slowed shortly after training.

Automaticity

The results of this study also bear on the issue of the loss of automaticity. Contemporary theories of automa-

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ticity conceptualize it as a memory phenomenon (Logan, 1988; Newell & Rosenbloom, 1981; Schneider, 1985), implying that repetition priming and automaticity are the same thing, and making the idea of forgetting very relevant. We can gain an understanding of the loss of automaticity resulting from an absence of practice (Logan, 1990) by examining the loss of repetition priming.

If automaticity is a function of memory, automaticity should show some of the characteristics of memory. Any decline in automatic performance over time should follow a forgetting curve, with performance a negatively accelerated function of time. Regarding the particular function, Wixted and Ebbesen (1991) evaluated exponential, hyperbolic, logarithmic, power, and exponential-power functions describing forgetting data from a variety of paradigms. They concluded that a power function consistently gave the closest description of the data. If the power function is a robust characteristic of memory, as they claim, the appropriateness of the automaticity-as-memory approach can be tested by examining the decline in automatic performance over time. If the memory-based approach is correct, the decline in performance should follow a power function.

Furthermore, obtaining a forgetting function for automaticity might provide a useful benchmark prediction, much like the ubiquitous power function speed-up. If it can be established that the loss of automaticity follows a power function, the prediction of the function will be a useful criterion in theory building. Just as a theory of automaticity must be able to predict a power function speed-up in performance, the forgetting function could be similarly useful in narrowing the field of contending theories and in constructing new theories.

Understanding the forgetting of automaticity is of practical value as well. Knowledge of the course of any loss of automaticity can guide the scheduling of any required retraining. This knowledge would be especially valuable for tasks in which practice is expensive, difficult, or dangerous. Knowledge of the forgetting function could allow retraining to be scheduled to maintain performance above a criterion with a minimum number of retraining sessions, which could be scheduled on the basis of the established form of the forgetting function.

Although subjects in the current research received less training than has been used in some other automaticity experiments, the work can be used to address the preceding issues regarding automaticity. The rationale relies on the assumption that automaticity is a relative state. Even with seemingly low levels of practice, performance is partially automatic. This contention is elaborated upon in the General Discussion.

EXPERIMENT 1

Four groups of subjects performed a lexical decision task in each of two sessions. The first session provided an opportunity to observe the buildup of priming over repetitions. If additional repetitions resulted in increased priming, a significant effect of presentations should be found. Such a finding would constitute a replication of Salasoo et al. (1985).

Specifically, in the first session, both words and nonwords were presented up to 16 times each. The data of Salasoo et al. (1985) indicated that priming was a negatively accelerated function of the number of repetitions and that 16 presentations would be sufficient to detect a similar result in our study. The retention intervals were scheduled increasingly far apart, in anticipation that the decline of priming might be negatively accelerated.

The second session was intended to answer two questions. First, a significant effect of retention interval would indicate that priming declined over the intervals tested. If found, this would replicate the findings of the studies surveyed by Sloman et al. (1988) and provide some assurance that the present study was comparable to other decay-of-priming studies. Second, the effect of the number of repetitions on the rate of decay in priming could be studied. An interaction of retention interval and number of presentations would indicate that the level of performance after an interval is affected by the amount of initial priming.

Method

Subjects. A total of 96 University of Illinois students were divided into four groups of 24, with each group assigned to a different retention interval. These subjects were assigned to the retention intervals on the basis of their ability to attend the second session, and they received course credit for participation.

Stimuli. The stimuli were 60 words and 60 nonwords, drawn randomly for each subject, from a pool of 340 five-letter words and 340 five-letter nonwords. The words were nouns selected from Kučera and Francis (1967), with a mean frequency of 75.27 per million and a range of 8–787 per million. The nonwords were formed by changing one letter of each word in the pool to create a pronounceable string. Not one of the nonwords that a particular subject saw was derived from the words given to that same subject.

The stimuli were presented and responses collected by an IBM AT or IBM XT microcomputer equipped with an Amdek 722 monitor. The stimuli were preceded by two lines of seven white dashes, one line above and one line below the point where the stimuli were to appear. White lowercase letters formed the stimuli, and each string was approximately 1.5 cm long. The stimuli appeared 33 spaces from the left edge and 13 lines down from the top of a standard 24 row × 80 column test screen. The orienting cue was displayed for 500 msec, after which the stimulus was presented for 500 msec. The subject had the opportunity to respond from the onset of the stimulus until 2,000 msec after the stimulus was presented. After the 2,000 msec had expired, the next trial began. If the subject failed to respond before the deadline, the trial was scored as incorrect.

Procedure. The subject was seated in front of the microcomputer and was instructed to indicate, as quickly as possible while remaining accurate, whether the string on the screen was a word or a nonword. The subjects indicated that a word had been displayed by pressing a key with one index finger and indicated a nonword by pressing another key with the other index finger. Half the subjects pressed the "Z" key on the keyboard to indicate that a stimulus was a word and the "/" key to indicate a nonword. These keys are the bottommost left and right keys on the AT keyboard and in virtually the same position on the XT keyboard. The key assignments were reversed for the other half of the subjects.

The amount of repetition priming was manipulated by varying the number of times a stimulus was presented. During training, each of the 60 words and 60 nonwords was presented 1, 2, 4, 8, or 16 times. For each number of presentations, 12 words and 12 nonwords were seen. These combinations of 12 words and 12 nonwords times (1 + 2 + 4 + 8 + 16) presentations yielded a total of 744 trials. The trials appeared in random order. After each block of 124 trials, a break was provided, and the subject restarted the presentations when ready.

Retention interval was manipulated by the use of four different experimental groups. Each subject returned after one of four retention intervals: 5 min, 8 h, 1 day, or 1 week. In the retention test session, the subjects were again instructed about the lexical decision task. The transfer stimuli comprised each of the old stimuli and 12 new words and 12 new nonwords. Each word and nonword was presented once. Because each stimulus was presented only once, 10 words and 10 nonwords not used in the experimental analysis preceded the experimental trials to provide a settling-in period for the subjects that would eliminate any "warm-up" effects that might obscure the effect of the experimental manipulations. The transfer session, then, totalled (12 + 12) [words and nonwords] × 6 [stimuli that received 0, 1, 2, 4, 8, or 16 prior presentations] + 20 [warm-up trials] = 164 trials. Upon completion of the test session, the subjects were debriefed and dismissed.

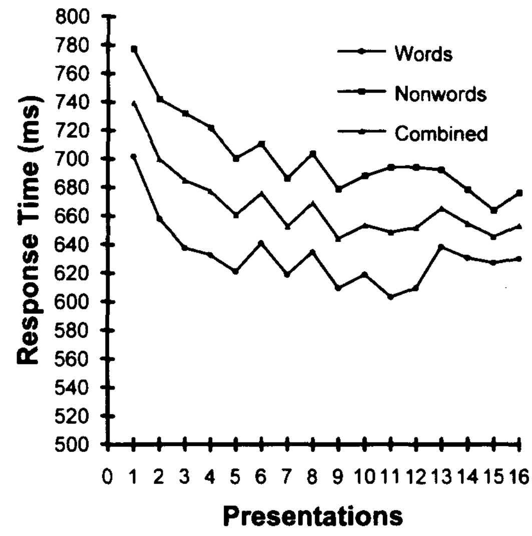

Figure 1. Response times in the first session of Experiment 1, as a function of number of presentations for words, for nonwords, and for words and nonwords combined.

Results

First session. The response times for correctly answered trials in the training session were subjected to a 16 (number of presentations) × 2 (lexical status) × 4 (retention interval group membership) mixed model analysis of variance (ANOVA). The effect of number of presentations was analyzed by computing mean response times for each number of presentations. Every stimulus was presented at least once, so the mean response time for Presentation 1 was based on the first presentation of all items. The mean response time for Presentation 2 was computed by using the response times for the second presentation of items that received two or more presentations. Mean response times were computed in the same manner for all presentations up to 16. The main effect of number of presentations was significant [$F(15,1380) = 34.04$, $MS_e = 3{,}444$, $p < .001$]. The subjects became faster with repetitions; that is, priming did occur, and it increased with subsequent presentations of the stimulus (see Figure 1). There was also an effect of lexical status [$F(1,92) = 177.70$, $MS_e = 21{,}454$, $p < .001$], with response times faster to words than to nonwords. Number of presentations interacted with lexical status [$F(15,1380) = 7.24$, $MS_e = 1{,}930$, $p < .001$]. Figure 1 shows that, over practice, the mean time to respond to words decreased by about 70 msec and the mean time to respond to nonwords decreased about 100 msec. The effects of retention interval group membership and of all its interactions were nonsignificant, indicating no differences among the groups before the retention interval.

The accuracy scores are presented in Table 1. The subjects performed the task at a high level of accuracy, with performance near the ceiling. Nevertheless, an ANOVA of the accuracy data corroborated the analysis of the response time data. Accuracy increased with presentations [$F(15,1380) = 9.44$, $MS_e = 395.31$, $p < .001$], and words were more accurately identified than nonwords [$F(1,92) = 20.94$, $MS_e = 271.95$, $p < .001$]. Finally, as in the response time analysis, number of presentations interacted with lexical status [$F(15,1380) = 6.08$, $MS_e = 25.56$, $p < .001$].

Table 1
Percent Correct in First Session of Experiments 1 and 2

Interval	Lexical Status	Presentation Number															
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
5 minutes	words	90	94	95	96	97	97	97	97	100	96	98	99	98	96	97	97
	nonwords	93	92	91	92	93	93	94	92	95	95	96	95	96	94	96	95
8 hours	words	87	93	95	94	96	96	95	95	95	97	98	98	97	97	96	96
	nonwords	90	89	91	90	95	91	93	89	94	93	94	95	93	93	90	95
1 day	words	90	93	95	95	97	97	95	95	96	98	98	96	97	94	94	91
	nonwords	92	91	92	91	94	92	93	91	95	92	91	91	91	91	91	92
1 week	words	91	95	96	96	97	96	96	97	97	98	98	97	97	97	97	97
	nonwords	93	92	92	93	95	94	95	93	98	98	96	95	92	94	93	96
1 month	words	88	93	94	93	95	96	95	95	97	98	96	98	93	94	96	95
	nonwords	92	91	93	92	94	95	95	93	95	94	92	97	97	95	92	94
2 months	words	89	93	93	92	97	96	94	96	98	97	97	97	92	96	96	97
	nonwords	93	91	92	93	93	94	94	93	96	93	96	97	96	93	94	95

Second session. The amount of priming was calculated by subtracting the mean response time to words and nonwords at each level of prior presentation during the first session from the mean response time to new words and nonwords in the second session. Priming was calculated for each subject, and the priming scores were then entered into a 5×2×4 mixed model ANOVA, with the factors lexical status, number of prior presentations, and retention interval. The main effect of lexical status was not significant [$F(1,92) = 3.50$, $MS_e = 20{,}257$, $p < .06$]. The main effect of retention interval was significant [$F(3,92) = 2.88$, $MS_e = 19{,}547$, $p < .05$], indicating that priming declined over time (see Figure 2). The effect of the number of presentations during training was significant [$F(4,368) = 48.36$, $MS_e = 2{,}141$, $p < .001$]; the more frequently an item was presented during training, the greater the priming during the retention test. Number of presentations and lexical status interacted significantly [$F(4,368) = 3.41$, $MS_e = 1{,}859$, $p < .01$]. All other effects were nonsignificant.

The accuracy scores from the second session are presented in Table 2. An ANOVA of the accuracy scores revealed that words were significantly more accurately identified than nonwords [$F(1,92) = 26.28$, $MS_e = 436.30$, $p < .001$]. Number of presentations was significant [$F(4,368) = 13.02$, $MS_e = 37.61$, $p < .001$]. Number of presentations also interacted with lexical status [$F(4,368) = 2.65$, $MS_e = 32.63$, $p < .05$]. The effect of retention interval did not reach significance. The failure to find an effect of retention interval in the accuracy data is unfortunate, but it is not unexpected. The subjects responded very accurately at all retention intervals, near ceiling. Because of this, there was little opportunity for significant differences to emerge.

The analysis of the accuracy data replicated all of the results of the response time data except for the effect of retention interval. Nor do the accuracy results contradict any of the response time results. Nothing in the accuracy data suggests that the conclusions drawn from the response time analyses are compromised by a speed–accuracy tradeoff.

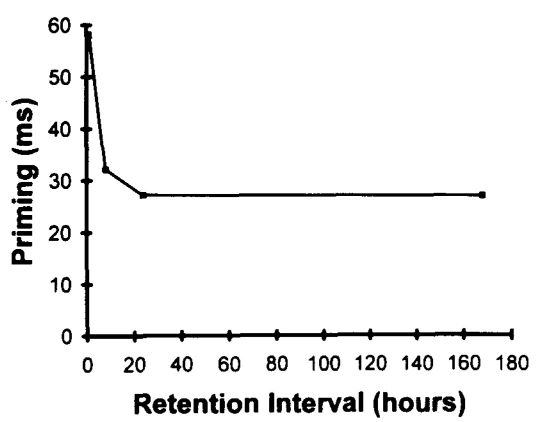

Figure 2. Priming in the second session of Experiment 1, as a function of retention interval.

Table 2
Percent Correct During Second Session of Experiments 1 and 2

Interval	Lexical Status	Number of Prior Presentations					
		0	1	2	4	8	16
5 minutes	words	86	93	94	97	94	98
	nonwords	93	94	96	95	91	97
8 hours	words	88	94	97	99	93	97
	nonwords	93	90	94	93	93	97
1 day	words	91	96	99	98	95	100
	nonwords	97	95	97	94	94	97
1 week	words	93	95	96	98	97	100
	nonwords	97	95	96	95	96	96
1 month	words	91	94	94	96	94	98
	nonwords	96	94	95	94	96	93
2 months	words	92	94	92	95	94	97
	nonwords	95	93	96	94	95	94

Discussion

Experiment 1 showed that the repetition effect grows in a continuous, negatively accelerated fashion, replicating the pattern in Salasoo et al. (1985). In addition, priming declined in a continuous fashion, quickest immediately after training. About half of the repetition priming effect disappeared within the first 24 h. This finding replicates the aggregate results of the studies reviewed by Sloman et al. (1988). Finally, the decline in priming over time was not affected by the number of presentations. The interpretation of this decline is not a straightforward matter, however, as we shall see later.

A consistent interaction of lexical status and number of presentations was also observed. Logan's (1988) instance theory of automaticity offers an explanation of the interaction. According to the theory, early in practice the solution to a problem is found by the execution of an algorithm, but late in practice the solution is found by recalling a previous solution in a single step. In the present case of lexical decision, the task may be initially performed by a serial, self-terminating search through the lexicon, which would explain why nonwords are initially identified more slowly than words. Later in practice, each stimulus will become directly associated with its status as a word or a nonword. The time to retrieve this association should not differ between words and nonwords; thus, times to identify words and nonwords should converge as task performance becomes increasingly based on memory retrieval.

EXPERIMENT 2

In Experiment 2, we took the same approach as we did in Experiment 1, but we tested subjects with a longer retention interval. Some of the subjects were retested 1 month later; others were retested 2 months later. If repetition priming declines as a monotonic function of time, the subjects should show less priming in Experiment 2 than they did in Experiment 1. If the decline in repetition priming is truly a negatively accelerated function, there should be a smaller difference in priming between the two groups in Experiment 2 than there was between groups in Experiment 1, even though the time between groups was longer in Experiment 2.

Method

Subjects. Forty-eight University of Illinois undergraduate students were tested. They were divided into two groups of 24, according to their ability to attend the second session. They were paid for their participation.

Stimuli and Design. The stimuli and design were identical to those in Experiment 1.

Procedure. The procedure was the same as in Experiment 1, with the exception that the retention intervals used were 1 and 2 months long.

Results

First session. The response times from correct trials were subjected to an ANOVA, and the results paralleled those of Experiment 1 (see Figure 3). The ANOVA showed that there was a main effect of number of presentations [$F(15,690) = 50.24$, $MS_e = 68{,}115$, $p < .001$], indicating that priming had occurred. Words were significantly faster than nonwords [$F(1,46) = 151.39$, $MS_e = 1{,}536{,}722$, $p < .001$]. Finally, lexical status interacted with number of presentations [$F(15,690) = 4.83$, $MS_e = 5{,}563$, $p < .001$]. All other effects were nonsignificant.

The accuracy scores from the first session are presented at the bottom of Table 1. An ANOVA of the accuracy scores produced results similar to the analysis of the response time data. The effect of number of presentations was significant [$F(15,690) = 7.51$, $MS_e = 33.13$, $p < .001$]. Number of presentations also interacted with lexical status [$F(15,690) = 3.38$, $MS_e = 33.00$, $p < .001$]. The significant effect of lexical status found in the response time analysis was not replicated in the accuracy data, however.

Second session. Priming scores were calculated in the same manner as in Experiment 1 and then subjected to an ANOVA (see Figure 4). There was a significant effect of number of presentations [$F(4,184) = 4.46$, $MS_e = 5{,}768$, $p < .005$]. With the exception of stimuli presented four and eight times in the 1-month group, the greater the number of times a stimulus had been repeated, the greater the stimulus was primed. A significant effect of lexical status indicated that there was more priming for words than for nonwords [$F(1,46) = 12.25$, $MS_e = 107{,}086$, $p < .001$]. Finally, there was a significant interaction of lexical status and number of presentations [$F(4,184) = 2.49$, $MS_e = 3{,}663$, $p < .05$]. All other effects were nonsignificant, including the interaction of presentations and retention interval.

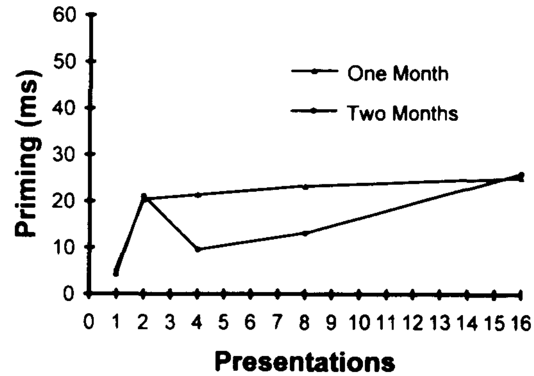

Figure 4. Priming in the second session of Experiment 2, as a function of number of presentations for retention intervals of 1 month (672 h) and 2 months (1,344 h).

The accuracy scores from the second session are presented at the bottom of Table 2. Again, two of the three significant effects found in the response time data were found in the accuracy data. Words were identified more accurately than were nonwords [$F(1,46) = 13.18$, $MS_e = 166.01$, $p < .001$]. The interaction of number of presentations and lexical status was significant [$F(4,184) = 2.97$, $MS_e = 46.36$, $p < .025$]. Neither the effect of number of presentations nor any other interactions reached significance.

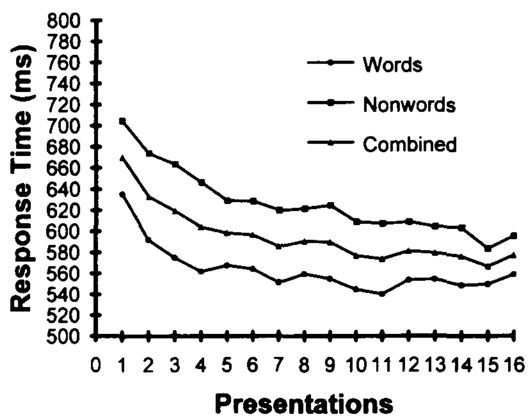

Figure 3. Response times in the first session of Experiment 2, as a function of number of presentations for words, for nonwords, and for words and nonwords combined.

Discussion

The results of Experiment 2 differed from those of Experiment 1 in two ways. First, the effect of retention interval was not significant in Experiment 2. Ironically, the failure to replicate is exactly what should have occurred if the processes at work in Experiment 1 were at work in Experiment 2. The amount of priming seemed to decline as a negatively accelerated function of retention interval in Experiment 1. The intervals were much longer in Experiment 2 than in Experiment 1, and a negatively accelerated function would differ very little over the two retention intervals. Although unlikely, a second, less interesting explanation for the failure to replicate exists. It could be that subjects in the 2-month group simply forgot more slowly than the subjects in the 1-month group. Nothing in the data allows one to rule out this possibility, but we favor the former explanation, nevertheless.

Second, the priming scores showed an effect of lexical status in Experiment 2 and not in Experiment 1. The only ready explanation of the discrepancy is to note the near-significance of the effect in Experiment 1 and attribute the difference to random error.

COMBINING THE DATA

The priming data from both experiments were then combined into one ANOVA. Before this was done, however, questions concerning possible differences between the subjects in the experiments were addressed. There may have been subject selection effects, because subjects willing to return to the lab 1 or 2 months later might have been different from those not willing to return even at shorter intervals. Also, subjects in the first experiment were given course credit in recompense, whereas those in the second experiment were paid.

The suspicion of subject effects was tested and confirmed by an ANOVA of the training data, with experiment as a between-subjects factor. The effect of experiment was significant [$F(1,142) = 15.66$, $MS_e = 344{,}595$, $p < .01$] indicating that subjects in the second experiment were faster overall. Experiment did not interact with any other factor, however, including number of presentations. The subjects in the second experiment may have responded faster, but they did not learn more quickly.

The absence of an interaction of group and presentations suggested that it would be possible to combine the data into one ANOVA. The main effect of experiment was not a difficulty, because priming scores were calculated within each subject. The combined data are presented in Figure 5.

The ANOVA of the retention of priming then proceeded, beginning with the examination of the response time data. The main effect of retention interval was significant [$F(5,138) = 3.39$, $MS_e = 16{,}495$, $p < .01$], indicating that savings declined over time. The effect of lexical status was also significant [$F(1,138) = 10.05$, $MS_e = 16{,}416$, $p < .01$], with words showing greater priming than nonwords. This is consistent with Logan (1990) and might be due to words' already having prior representations in memory. The effect of number of presentations during training [$F(4,552) = 49.18$, $MS_e = 1{,}859$, $p < .001$] was significant; the more frequently an item was presented during training, the greater the priming in the retention test. Lexical status and number of presentations interacted significantly [$F(4,552) = 5.30$, $MS_e = 1{,}927$, $p < .001$].

The interaction of presentations and retention interval was then tested. Before this could be done, however, a floor effect in the data from the once-presented items needed to be addressed. Priming from these items had declined to zero, as low as it could go, before the end of the experiment, whereas oft-presented items still had priming to lose. Inclusion of data from the once-presented items in the analysis would have promoted a spurious conclusion that there was an interaction of presentations and retention interval. Therefore, the interaction was tested with the data from the once-presented items excluded. The interaction was still significant [$F(15,414) = 2.27$, $MS_e = 1{,}601$, $p < .005$]. Items that received few presentations lost less of the priming they had accrued than did items that had been presented many times. Items that received many repetitions lost much of the priming that extensive repetition brought. An exception to this trend should be mentioned, however; items that received 8 presentations lost more priming than did items that received 16 presentations.

In interpreting the interaction of presentations and retention interval, one must remember that it is an empirical result. Priming as an empirical phenomenon—the reduction in response time associated with repeated presentations—declines at different rates, depending on the initial amount of priming. The data themselves do not say whether the theoretical entity of priming, perhaps the activation level of a node in semantic memory, declines at a rate dependent on the initial number of presentations. That sort of conclusion requires a theoretical account that relates experimental performance to underlying theoretical entities. These data could indicate the presence or absence of an interaction, depending on the theory within which they are interpreted. For a discussion of this in the context of forgetting rates, see Bogartz (1990a, 1990b).

The combined priming accuracy data were then examined in an ANOVA. The effect of retention interval was significant [$F(5,138) = 2.52$, $MS_e = 313.80$, $p < .05$]. Words were identified better than nonwords [$F(1,138) = 37.8$, $MS_e = 346.20$, $p < .001$]. The effect of number of presentations was significant [$F(4,552) = 11.99$, $MS_e = 37.50$, $p < .001$]. Only one interaction was significant, that of number of presentations and lexical status [$F(4,552) = 4.39$, $MS_e = 37.20$, $p < .005$].

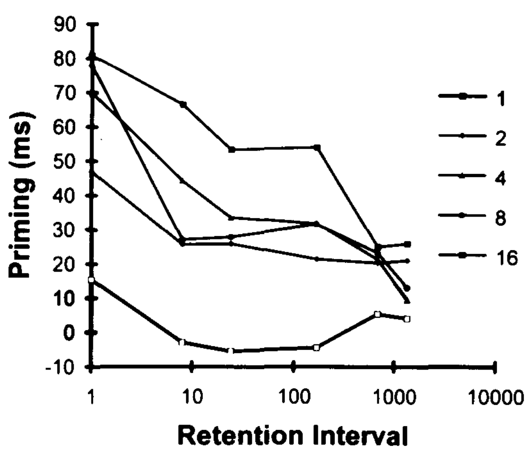

Figure 5. Priming in the combined data of Experiments 1 and 2, as a function of retention interval for each level of number of presentations.

AUTOMATICITY

These data bear on automaticity as well as priming. Several theories of automaticity (Logan, 1988; Newell &

Rosenbloom, 1981; Schneider, 1985) explain automaticity as a memory phenomenon. In these theories, automaticity is defined as task performance based on the retrieval of the correct solution from memory rather than the use of an algorithm or weak method approach to solve the problem. This means that after the correct response to an item has been found even once, that item may then be processed automatically. The hundreds or thousands of trials typical of many automaticity studies increase the likelihood that the solution will be retrieved from memory rather than computed from first principles, and they increase the number of items for which a solution is available in memory. Large numbers of trials are not required for automatic performance, nor do they guarantee it (Logan, 1988; Logan & Klapp, 1991).

Furthermore, these theories hold that automaticity is not a discrete state, but a continuum. Performance may be more or less automatic, depending on the probability with which the solution will be recalled from memory, with the restriction that performance will be more automatized on trial $N+M$ than on trial N. In particular, in Logan's (1988) instance theory, on each trial, memory traces and an algorithm, each with normally distributed finishing times, race to provide a solution. Therefore, because, on any particular trial, regardless of the amount of practice, the algorithm could finish before an appropriate memory trace is found, it is inappropriate to describe task performance in general as being either automatic or not automatic. Even when performance has reached asymptote, the solution on a trial may be supplied by the algorithm, not memory retrieval. Task performance in general is more or less automatic, depending on the probability that the solution will be retrieved from memory. This means that a subject's performance need not be at asymptote before automaticity can be studied.

This approach to automaticity defines automatic performance by the processes underlying it, not by characteristics of the data produced. The diagnosis of automaticity is therefore difficult. Nevertheless, all the theories have in common at least two predictions about the nature of the data during the development of automaticity. First, because each trial adds to memory, they predict that performance should be faster on trial $N+1$ than on trial N. Second, each contains mechanisms which predict that the development of automaticity will follow a power function.

The present data indicate in two ways that the subjects were becoming automatized. First, although not perfectly monotonic, performance tended to improve on every trial. Second, a power function was fit to the data from the first session by using a least squares procedure (Wilkinson, 1988). The fits were very good. When collapsed over groups and lexical status, the fitted equation was $601.254 + 116.042\,N^{-.598}$, $r^2 = .950$, root mean squared deviation (RMSD) = 5.540. Thus, both predictions of memory-based theories of automaticity were met by the data.

The Forgetting Function

If automaticity is memory based, characteristics of memory should be discernible in automaticity data. If one assumes that the speed of the algorithm is constant over retention intervals, the decline in automatic performance should be a form of forgetting function and should therefore be similar to other forgetting functions. In particular, the decline in performance should follow a power function (Wixted & Ebbesen, 1991). Each of the common negatively accelerated functions identified by Wixted and Ebbesen was fitted to the decline in priming data for word, nonword, and combined data, collapsed over presentations, generating the results presented in Table 3.

Of the functions considered by Wixted and Ebbesen (1991), the power function provided the closest fit in the case of the words and combined data, although the fit was not as good in the case of the nonwords. Averaged over the word, nonword, and combined data, the power function provided the best description of the data. The decline in automatic performance is of the same form as the forgetting function, supporting the memory-based approach to automaticity.

GENERAL DISCUSSION

The present experiments have clarified the relation among priming, retention intervals, and number of repetitions. Replicating Salasoo et al. (1985), the repetition effect was found to build up in a negatively accelerated manner with increasing repetitions.

This priming then declined over time in a similarly continuous fashion. The greatest loss occurred initially, as in Sloman et al. (1988), with the loss being less dramatic beyond the first day. Priming was still present 2 months after the first session.

In general, it was found that the number of presentations did not affect the decline of priming over time. However much an item was primed, the priming tended to decrease at the same rate. This is in keeping with the results of Slamecka and McElree (1983), who argued from their

Table 3
Root Mean Squared Deviation of Candidate Forgetting Functions

Function		Data Fit: Combined	Word	Nonword	M
Power	$y=a\ \text{delay}^b$	3.821	11.488	8.459	7.923
Logarithmic	$y=a-b\ \log(\text{delay})$	5.489	13.142	7.409	8.680
Exponential	$y=a\ \exp(bt)$	9.902	16.295	9.573	11.923
Hyperbolic	$y=1/(a+b\ \text{delay})$	9.455	16.213	8.170	11.279
Exponential power	$y=a\ \exp(-2b\ \text{delay}^{.5})$	8.293	17.843	7.703	11.280

own data, and from previously published data, that forgetting was independent of the degree of initial learning. When the response time priming data from Experiments 1 and 2 were combined and analyzed, however, there was a significant interaction of presentations and retention interval. Items that had been repeated many times lost more priming than did items that had received fewer repetitions. This result is curious, for it did not occur when the experiments were examined separately, nor did it appear in the accuracy data. Furthermore, it is contrary to the results of Slamecka and McElree.

The meaning of this exceptional result is unclear. The exceptional result may have been due to random error. On the other hand, the result may have been absent from the individual experiments' results because of a lack of statistical power in the individual experiments' analyses. The fact that the result seems to be at odds with Slamecka and McElree (1983) should not be taken too seriously. Slamecka and McElree found the absence of interaction when the dependent variable was an accuracy measure; they did not examine any speed measures. When accuracy measures are examined, the results of the present research are consistent and in agreement with Slamecka and McElree. It may be that speed and accuracy measures are affected differently by the joint effects of the degree of initial learning and time.

Whatever the source of the significant interaction, it must be remembered that this is simply an empirical result. What this result says about the joint effects of time and repetitions on underlying psychological mechanisms depends on the particular theory relating the underlying theoretical mechanisms to observable performance.

The most consistent finding in the present experiments was the interaction of number of presentations and lexical status. Every analysis of the data showed that nonwords benefited from practice more than words. As discussed in Experiment 1, this finding is readily explained by Logan's (1988) instance theory of automaticity.

Although the present study can be understood as a study of priming and memory, it can also be interpreted as a study of automaticity, for there are empirical and theoretical grounds for believing that the same mechanisms underlie both phenomena (Logan, 1988, 1990; Newell & Rosenbloom, 1981; Schneider, 1985). The present experiments lend additional support to the idea that automaticity is a memory phenomenon. Just as information in memory is forgotten, so is automaticity. The power function forgetting curve that Wixted and Ebbesen (1991) found to be a robust characteristic of memory was found to fit the decline in automaticity very well. In addition to providing evidence for the hypothesis that automaticity is a memory phenomenon, the power function forgetting curve can serve as a benchmark prediction for the development of comprehensive theories of automaticity.

To date, no other theories of automaticity have been adapted to account for forgetting data, but this does not mean that they are incapable of being adapted to account for the decline in automaticity over time. For example, Schneider's (1985) connectionist model might implement weight decay or the lesioning of units to account for a decline in automaticity. Within Newell and Rosenbloom's (1981) model, each production in memory might have a probability of being forgotten, dependent on time since learned or time since last use. The decline might be accounted for with Logan's (1988) instance theory by postulating that instances are gradually lost over time.

Whatever the mechanisms that might be used to make current or new models of automaticity account for forgetting, the attempts to do so will lead to richer, broader theories of automaticity, and further the tactic of using the well-developed knowledge base of the memory literature to understand automaticity.

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