Bulletin of the Psychonomic Society
1990, 28 (2), 97-100

Strength and duration of word-completion priming as a function of word repetition and spacing

KAREN S. CHEN
University of California School of Medicine, La Jolla, California

and

LARRY R. SQUIRE
Veterans Administration Medical Center, San Diego
and University of California School of Medicine, La Jolla, California

We assessed the effects of stimulus repetition and spacing on the strength and duration of word-completion priming. Subjects studied words presented 4, 16, or 32 times and were then given tests of word-stem completion and recognition memory. The words were presented in one session with an immediate, 2-h, or 24-h test; or in four sessions spaced 2 h apart with a test 24 h after the final session. Other subjects were presented the same set of words 1, 2, or 4 times and were tested immediately after word-list presentation. The subjects tested in the immediate conditions exhibited priming, but the subjects in the delay or spaced conditions did not. The subjects exhibited stronger priming effects after four repetitions of the list words than after only one or two repetitions; however, priming effects were not further increased by 16 or 32 repetitions. In contrast, recognition memory performance declined only slightly across 24 h and improved as the number of repetitions increased from 1 to 32. Word-completion priming following presentation of single words appears to be short-lived and may reach a maximum after a few presentations.

On conventional memory tests, subjects are explicitly asked to recall or recognize previously presented material. However, the effects of prior experience can also be assessed implicitly, as in tests of word priming. Priming is a facilitation in the processing of recently encountered material; it can be measured by tests of word-stem completion, fragment completion, lexical decision, or word identification. In the word-stem completion task, subjects are presented with a list of words and then instructed to complete a list of three-letter word stems with the first word that comes to mind beginning with the three letters (e.g., MOTEL is presented; MOT must be completed). Priming is evidenced by the tendency to complete stems to form the recently presented words rather than other words.

Studies of normal subjects and neurological patients with memory impairments have suggested that priming tasks and tests of recall and recognition measure two different kinds of memory, sometimes termed declarative and nondeclarative (see Shimamura, 1986; Squire, 1987; Squire & Zola-Morgan, 1988). Evidence for a distinction between two kinds of memory also comes from studies showing that factors that influence recognition memory do not affect priming (e.g., the kind of study task engaged in during list presentation; see Graf & Mandler, 1984; Graf, Mandler, & Haden, 1982; Jacoby & Dallas, 1981). Conversely, priming is diminished by presenting words in one modality and then testing in a different modality, a condition that typically does not affect performance on explicit memory tests (Clarke & Morton, 1983; Graf, Shimamura, & Squire, 1985; Kirsner, Milech, & Standen, 1983; Roediger & Blaxton, 1987; Scarborough, Gerard, & Cortese, 1979). Finally, Hayman and Tulving (1989) demonstrated that recognition memory is more closely related to cued recall than to priming.

Results with tasks such as perceptual identification or lexical decision suggest that priming effects for single words can last for days (Jacoby, 1983; Jacoby & Dallas, 1981). In the case of the word-completion task, when the word stems have only one common solution (e.g., JUICE is presented; JUI must be completed), priming persists for days or weeks (Light, Singh, & Capps, 1986; Squire, Shimamura, & Graf, 1987; Tulving, Schacter, & Stark, 1982; Warrington & Weiskrantz, 1978). By contrast, when the word stems have multiple solutions (e.g., MOTEL is presented; MOT must be completed), word completion effects disappear within 2 h (Diamond & Rozin, 1984; Graf & Mandler, 1984; Graf, Squire, & Mandler, 1984; Shimamura & Squire, 1984; Squire et al., 1987). Although the duration of priming seems to depend on the type of test and stimulus materials, word-completion priming ap-

This research was supported by the Medical Research Service of the Veterans Administration, NIMH Grant MH24600, the Office of Naval Research, the McKnight Foundation, and an NSF predoctoral fellowship to Karen S. Chen. We thank Arthur Shimamura and Joyce Zouzounis for their assistance. Requests for reprints should be sent to Larry R. Squire, Veterans Administration Medical Center (V116A), 3350 La Jolla Village Drive, San Diego, CA 92161.

pears short-lived when the word stems have multiple solutions.

Word-completion priming might last longer when subjects have frequent encounters with the same stimuli. Skill learning, another form of nondeclarative memory, benefits from repetition. After sufficient practice, a skill can persist for a long time. The duration of priming might also be affected by whether repeated encounters are massed or spaced. Spaced training trials are known to improve recall and recognition performance (cf. McGeoch & Irion, 1952; Underwood, 1961) and to result in a longer-lasting memory of habituation in the invertebrate (Carew, Walters, & Kandel, 1974). Little is known about the effects of spaced training on priming. In the following experiments, we assessed the effect of repeated presentations of words (1, 2, 4, 16, or 32 times) and spacing the presentations on subsequent word-completion performance.

METHOD

Subjects

Forty-eight subjects (21 men and 27 women; mean age = 45.2 years, range = 22-62; mean education = 15.7 years, range = 11-21) were recruited from volunteers, employees, and medical outpatients at the San Diego Veterans Administration Medical Center. Each subject was assigned to one of five different conditions. To assess word completion following 4, 16, or 32 repetitions, subjects were tested immediately (N = 10), 2 h (N = 8), or 24 h after massed study trials (N = 10); or 24 h after spaced study trials (N = 10). To assess word completion following 1, 2, or 4 repetitions, another group was tested immediately after massed study trials (N = 10).

Materials

Forty words, four to eight letters long, were selected from Webster's New World Dictionary (average frequency of occurrence per million = 47; see Kučera & Francis, 1967). The first three letters of each word, the stem, appeared only once among the set of selected words, and each stem could be completed to form at least 10 common words. The 40 target words were divided into four lists of 10 words and printed individually on index cards in .25-in. high capital letters. These cards were then duplicated to construct four different decks of 520 cards each. In each deck of 520 cards, one 10-word list was repeated four times, a second was repeated 16 times, a third was repeated 32 times, and the fourth was not presented at all. The assignment of each 10-word list to each of these conditions (0, 4, 16, or 32 repetitions) was balanced across the four decks. To assess word completion after 1, 2, or 4 repetitions, four additional decks of 70 cards each were constructed in the same manner as the 520-card decks, except that the four 10-word lists were repeated 0, 1, 2, or 4 times instead of 0, 4, 16, or 32 times.

Words were arranged in each of the 520-card decks so that the first 13 cards included 8 words that would eventually appear a total of 32 times, 4 words that would appear 16 times, and 1 word that would appear 4 times. No word was repeated within these 13-word sequences. This same arrangement was then maintained for 130 cards (10 sets of 13-word sequences), and each 520-card deck consisted of four repetitions of the 130-card sequence. On the average, 28 cards (range = 2-130) intervened between repetitions of the same word. Words were arranged in each 70-card deck in a manner similar to the one described for the 520-card decks. The first 7 cards included 4 words that would appear 4 times, 2 words that would appear 2 times, and 1 word that would appear only once. Each 70-card deck consisted of 10 sets of 7-word sequences. On the average, 16 cards (range = 2-53) intervened between repetitions of the same word.

The word-completion test consisted of 100 stems: 30 stems from words that had been presented, 10 stems from words that had not been presented but had served as target words for other subjects and therefore permitted a measure of baseline guessing rates, and 60 filler stems, selected according to the same criteria as the other stems, and not scored. The recognition memory test consisted of 60 words: 30 target words and 30 distractor words (selected according to the same criteria) intermixed on a sheet of paper.

Procedure

Each subject was shown a deck of either 520 or 70 index cards, 1 card at a time. Assignment of the four different decks to subjects was balanced within each experimental group. Either the 520 cards were presented at one sitting (for the immediate 2-h and 24-h tests with massed study trials), or 130 cards were presented at each of four sittings spaced 2 h apart (for the 24-h test with spaced study trials). The 70 cards were presented at one sitting, and the tests were given immediately following card presentation. For the first quarter of the deck of words, the subjects were asked to categorize each word as "concrete" or "abstract." For the second, third, and fourth quarters of the deck, the subjects were asked to judge whether the words were pleasant or unpleasant, strong or weak, or common or uncommon, respectively. Presentation of the cards was paced according to the speed with which these judgments were made (2-3 sec per card).

Following presentation of the study cards, all subjects received the same tests of word completion and word recognition. These were given immediately, 2 h, or 24 h after the cards were presented; or (in the case of the spaced study trials condition) 24 h after the fourth and final presentation. For the word-completion test, the subjects were instructed that the test was a word puzzle. They were asked to complete each word stem with the first word that came to mind beginning with these letters, but not to use any proper nouns. If a proper noun was generated, an alternative response was requested. The subjects were given as much time as they needed to finish the test. After the word-completion test, the subjects were given a recognition memory test. The subjects were instructed to circle the words that had been presented earlier. Finally, all subjects were asked whether they detected any connection between the word-completion test and the words they had seen earlier on cards.

At the beginning of testing, it was emphasized that three different and independent tests would be given (this referred to the judgment, completion, and recognition memory tasks, but the tests were not named or explained in advance). This procedure minimized the chance that a subject would detect a connection between the word-completion test and the words that had been presented.

RESULTS

A strict criterion was used in scoring the word-completion task: Words were scored as completions only if they had appeared in the presentation list in exactly the same form. Alternative scoring methods did not alter the pattern of results. All subjects were able to complete all 100 stems with words. For each subject, the probability of forming the 10 target words that had not been presented served as an estimate of baseline guessing rate. Figure 1 shows word-completion performance and baseline scores for subjects that had been given 4, 16, or 32 repetitions of the target words. In the immediate test condition, word completion for all three repetitions was significantly above baseline [46.7% vs. 10.0%; $t(9) = 7.2, p < .01$]. There was no effect of repetition [$F(2,18) = 1.6, MS_e = 267.8$]. Two hours after word presentation, completion performance had declined to baseline levels [13.3% vs. 10.0%; $t(7) = 0.7$]. Performance was similar across the three levels of repetition [$F(2,14) = 0.3, MS_e = 100.6$]. Word completion 24 h after either massed or spaced study trials was also close to baseline [17.3% vs. 10.0%, $t(9) = 1.8$, $p = 0.1$, and 14.0% vs. 10.0%, $t(9) = 1.4, p > 0.1$, respectively]. There was no effect of repetition for either group (Fs < 0.8). Separate comparisons between groups showed that word completion was higher in the immedi-

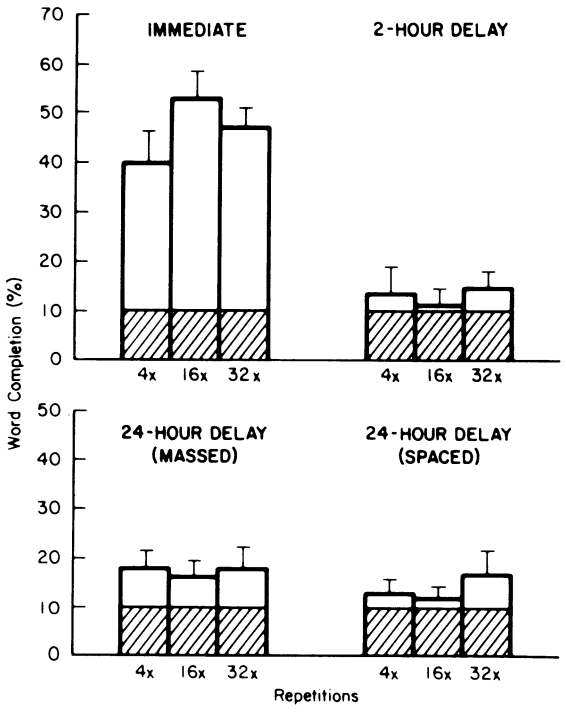

Figure 1. Word-completion performance from three-letter stems. (Five hundred twenty words were presented; 30 different words were repeated 4, 16, or 32 times. Word completion was tested immediately after word presentation, after 2 h, after 24 h, or 24 h after four study sessions spaced 2 h apart. The shaded areas show baseline performance, which was calculated separately for each test condition. Brackets show standard error of mean.)

ate test condition than in any of the other three conditions (all $ps < .001$). Word completion in the three delayed conditions was similar (all $ps > 0.1$).

Figure 2 shows word-completion performance and the baseline score for subjects that had been given 1, 2, or 4 repetitions of the target words. Word completion across the three conditions was significantly above baseline [32.3% vs. 9.0%; $t(9) = 4.9$, $p < .001$]. There was an effect of repetition [$F(2,18) = 7.09$, $MS_e = 162.8$, $p < .01$].

Table 1 shows results on the recognition memory test (average of the percentage of correct hits and correct rejections). After 4, 16, or 32 repetitions, recognition performance was high in all four groups, declining slightly but significantly during the 24 h after word presentation [$F(2,25) = 3.6$, $MS_e = 40.1$, $p < .05$, for a comparison of the immediate, 2-h, and 24-h with massed study trials conditions]. Scores in the massed and spaced presentation groups did not differ significantly [$F(1,18) = .02$, $MS_e = 82.4$]. In contrast to the results for word completion, recognition memory scores showed a clear effect of repetition [$F(2,68) = 23.6$, $MS_e = 6.7$, $p < .001$, for a comparison involving all four conditions]. After 1, 2, or 4 repetitions, there was also a clear effect of repetition [$F(2,18) = 7.5$, $MS_e = 63.1$, $p < .01$]. Words repeated twice were recognized better than words repeated only once [$t(9) = 3.6$, $p < .01$]. There was no significant difference between words repeated twice and four times [$t(9) = 1.3$, $p > .10$]. When recognition memory performance was evaluated using d' to estimate recognition memory, the results were identical.

Forty-two of the 48 subjects reported at the conclusion of testing that they were unaware of the connection between the presentation of the study words and the subsequent word-completion test. The subjects viewed the completion test as a word puzzle or as a distraction task between word presentation and an anticipated, later memory test. The average word-completion score for the 6 subjects that suspected a connection was within 3% of the average score for the other subjects.

DISCUSSION

The results can be summarized by stating that long-lasting word-completion effects failed to occur. Four or more repetitions produced a stronger priming effect than one or two repetitions did. However, even after as many as 32 repetitions of a single word, priming was not significantly above baseline levels at either 2 or 24 h after word presentation. Word-completion performance was numerically greater than baseline levels in all delay conditions. This finding raises the possibility that a small, residual effect of word presentation might persist. However, baseline levels were exceeded by only a small and nonsignificant amount in each case (mean = 5%). In addition, the spacing of word presentation across four sessions did not affect word-completion performance. These results suggest that word-completion effects based on presentation of single words are ordinarily short-lasting.

Two previous studies (Graf & Mandler, 1984; Jacoby & Dallas, 1981) reported differences in the levels of word priming for words presented once and words presented twice. The first study (Graf & Mandler, 1984) involved the same word-completion task that was used in the present study and resulted in a small (5%), marginally significant ($p = .06$) advantage of two presentations as compared with a single presentation. The second study (Jacoby & Dallas, 1981) resulted in a significant advantage of two presentations over one presentation on a perceptual identification task. These findings are in agreement with the present results in suggesting that priming effects for single words may be strengthened to some extent by a few repetitions.

The level of word-completion priming obtained in the present study after one or two repetitions (27%, 26%) was lower than the level of priming obtained in previous studies with similar materials (one repetition: 47%, Salmon, Shimamura, Butters, & Smith, 1988; two repetitions: 53%,

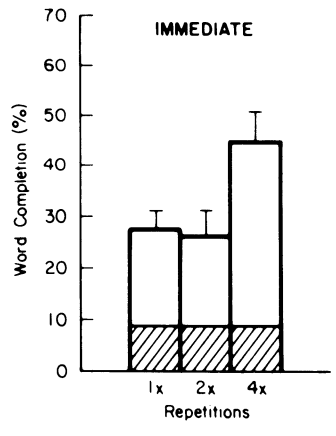

Figure 2. Word-completion performance from three-letter stems. (Seventy words were presented; 30 different words were repeated one, two, or four times. Word completion was tested immediately after word presentation. The shaded area shows baseline performance, which was calculated separately for each test condition. Brackets show standard error of mean.)

Table 1
Recognition Memory

No. of Repetitions	Condition			
	Immediate	2 h	24 h (massed)	24 h (spaced)
		Experiment 1		
4	93.3±1.3	96.3±1.2	89.9±1.8	90.5±2.1
16	96.3±1.3	97.5±0.7	94.3±1.6	94.0±1.9
32	98.3±0.8	97.5±0.7	94.3±1.6	94.5±1.8
		Experiment 2		
1	79.7±4.5			
2	89.2±3.3			
4	93.0±2.2			

Note—Scores are percent correct (correct hits plus correct rejections ± standard error of mean).

Shimamura, Salmon, Squire, & Butters, 1987). This difference may be due to the number of words presented at study (70 in the current experiment, vs. 15 in the earlier ones) and the number of word stems presented at test (100 in the current experiment, vs. 20 in the earlier ones).

Relatively long-lasting priming effects of single words have been reported in perceptual identification tasks, in lexical decision tasks, and in word-fragment completion tasks with one solution (Jacoby, 1983; Jacoby & Dallas, 1981; Scarborough, Cortese, & Scarborough, 1977; Tulving et al., 1982). It is thus possible that priming effects for single words sometimes persist and that some techniques will prove to be better than others at revealing long-lasting effects. Also, it is often difficult to disguise the relationship between the word lists presented for study and the priming test when normal subjects are tested. If subjects detected such a relationship, they might engage an explicit (declarative) memory strategy to retrieve a study word. One useful approach to this issue is to ask whether amnesic patients exhibit long-lasting priming for single words, because they provide a measure of priming that is minimally affected by explicit memory strategies (Squire et al., 1987).

Priming effects may last longer when units larger than single words are primed (e.g., related word pairs, idioms, or ideas). In the case of related word pairs (e.g., the pair TABLE-CHAIR is presented; the subject must free associate to TABLE), priming effects disappeared within 2 h (Shimamura & Squire, 1984). It is not known whether this effect could last longer with repeated presentations. Recently, amnesic patients were shown to exhibit long-lasting facilitation of single-word solutions to riddles following a single presentation of the riddle and its solution (McAndrews, Glisky, & Schacter, 1987). The facilitation had many of the features of priming effects. In this case, a single word (the solution) was activated by a phrase to which it was ordinarily only weakly associated.

In summary, when measured by word-completion tasks, priming effects following presentation of single words are short-lasting. Even frequent, spaced repetitions of words did not produce long-lasting effects. It remains possible that variables other than repetition or spacing could prove effective in establishing long-lasting priming. Moreover, certain techniques for testing memory implicitly, other than word completion, do appear to detect long-lasting effects of single words. In these cases, studies of amnesic patients would also be useful to evaluate the possible contribution of explicit memory strategies.

REFERENCES

Carew, T. J., Walters, E. T., & Kandel, E. R. (1981). Classical conditioning in a simple withdrawal reflex in Aplysia californica. *Journal of Neuroscience*, **1**, 1426-1437.

Clarke, R., & Morton, J. (1983). Cross modality facilitation in tachistoscopic word recognition. *Quarterly Journal of Experimental Psychology*, **35A**, 79-96.

Diamond, R., & Rozin, P. (1984). Activation of existing memories in the amnesic syndromes. *Journal of Abnormal Psychology*, **93**, 98-105.

Graf, P., & Mandler, G. (1984). Activation makes words more accessible, but not necessarily more retrievable. *Journal of Verbal Learning & Verbal Behavior*, **23**, 553-568.

Graf, P., Mandler, G., & Haden, P. E. (1982). Simulating amnesic symptoms in normals. *Science*, **218**, 1243-1244.

Graf, P., Shimamura, A., & Squire, L. R. (1985). Priming across modalities and across category levels: Extending the domain of preserved function in amnesia. *Journal of Experimental Psychology: Learning, Memory, & Cognition*, **11**, 386-396.

Graf, P., Squire, L. R., & Mandler, G. (1984). The information that amnesic patients do not forget. *Journal of Experimental Psychology: Learning, Memory, & Cognition*, **10**, 164-178.

Hayman, C., & Tulving, E. (1989). Contingent dissociation between recognition and fragment completion: The method of triangulation. *Journal of Experimental Psychology: Learning, Memory, & Cognition*, **15**, 228-240.

Jacoby, L. L. (1983). Perceptual enhancement: Persistent effects of an experience. *Journal of Experimental Psychology: Learning, Memory, & Cognition*, **9**, 21-38.

Jacoby, L. L., & Dallas, M. (1981). On the relationship between autobiographical memory and perceptual learning. *Journal of Experimental Psychology: General*, **110**, 306-340.

Kirsner, K., Milech, D., & Standen, P. (1983). Common and modality-specific processes in the mental lexicon. *Memory & Cognition*, **11**, 621-630.

Kučera, M., & Francis, W. (1967). *Computational analysis of present-day American English*. Providence, RI: Brown University Press.

Light, L. L., Singh, A. A., & Capps, J. L. (1986). Dissociation of memory and awareness in young and older adults. *Journal of Clinical & Experimental Neuropsychology*, **8**, 62-74.

McAndrews, M. P., Glisky, E. L., & Schacter, D. L. (1987). When priming persists: Long-lasting implicit memory for a single episode in amnesic patients. *Neuropsychologia*, **25**, 497-506.

McGeoch, J. A., & Irion, A. L. (1952). *The psychology of human learning* (2nd ed.). New York: Longmans, Green & Co.

Roediger, H. L., & Blaxton, T. A. (1987). Retrieval modes produce dissociations in memory for surface information. In D. S. Gorfein & R. R. Hoffman (Eds.), *Memory and cognition processes: The Ebbinghaus Centennial Conference* (pp. 349-377). Hillsdale, NJ: Erlbaum.

Salmon, D. P., Shimamura, A. P., Butters, N., & Smith, S. (1988). Lexical and semantic priming deficits in patients with Alzheimer's disease. *Journal of Clinical & Experimental Neuropsychology*, **10**, 477-494.

Scarborough, D. L., Cortese, C., & Scarborough, H. S. (1977). Frequency and repetition effects in lexical memory. *Journal of Experimental Psychology: Human Perception & Performance*, **3**, 1-17.

Scarborough, D. L., Gerard, L., & Cortese, C. (1979). Accessing lexical memory: The transfer of word repetition effects across task and modality. *Memory & Cognition*, **7**, 3-12.

Shimamura, A. P. (1986). Priming effects in amnesia: Evidence for a dissociable memory function. *Quarterly Journal of Experimental Psychology*, **38A**, 619-644.

Shimamura, A. P., Salmon, D. P., Squire, L. R., & Butters, N. (1987). Memory dysfunction and word priming in dementia and amnesia. *Behavioral Neuroscience*, **101**, 347-351.

Shimamura, A. P., & Squire, L. R. (1984). Paired-associate learning and priming effects in amnesia: Neuropsychological study. *Journal of Experimental Psychology: General*, **113**, 556-570.

Squire, L. R. (1987). *Memory and brain*. New York: Oxford University Press.

Squire, L. R., Shimamura, A. P., & Graf, P. (1987). Strength and duration of priming effects in normal subjects and amnesic patients. *Neuropyychologia*, **25**, 195-210.

Squire, L. R., & Zola-Morgan, S. (1988). Memory: Brain systems and behavior. *Trends in Neurosciences*, **11**, 170-175.

Tulving, E., Schacter, D. L., & Stark, H. A. (1982). Priming effects in word-fragment completion are independent of recognition memory. *Journal of Experimental Psychology: Learning, Memory, & Cognition*, **8**, 336-342.

Underwood, B. J. (1961). Ten years of massed practice on distributed practice. *Psychological Review*, **68**, 229-247.

Warrington, E. K., & Weiskrantz, L. (1978). Further analysis of the prior learning effect in amnesic patients. *Neuropsychologia*, **16**, 169-177.

(Manuscript received July 24, 1989.)