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The effect of spaced practice on explicit and implicit memory

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The spaced-practice effect refers to the strong and pervasive positive influence on long-term explicit memory which results from interposing at least one other item between the repetitions of any to-be-remembered item in a list-learning paradigm. Limited prior empirical evidence suggests that spaced practice could also have a similar positive effect on implicit memory performances, as revealed through a tachistoscopic identification task.

Four experiments involving another implicit memory task, namely a perceptual clarification procedure, were conducted to test for the effect of spaced practice with greater methodological control than previously used. Low-frequency words were displayed to subjects under a variety of conditions including incidental (Expts 1 and 2) and intentional (Expts 3 and 4) learning instructions. Although spacing regulated to a large extent the performances in subsequent free recall (Expt 2) or recognition (Expts 1, 3, 4) control tasks, the advantage of spaced over massed items in the perceptual clarification procedure was always small in magnitude, and only reached significance in the last experiment. Overall analysis of the data shows with a reasonably high degree of certitude that spaced practice exerts a real but probably slight and fluctuating effect upon implicit memory performance.

Studies of human memory traditionally focus on tests such as free recall, cued recall, and recognition, in which conscious recollection of items through some sort of directed controlled search into stored information is required. However, in the last few years, an increasing number of investigators have become aware that effects of memory can also be measured in tasks such as lexical decision (e.g. Carroll & Kirsner, 1982), word fragment completion (e.g. Tulving, Schacter & Stark, 1982), verbal association (e.g. Cofer, 1967), the spelling of homophones (e.g. Jacoby & Witherspoon, 1982), tachistoscopic identification (e.g. Murrell & Morton, 1974), or picture naming (Carroll, Byrne & Kirsner, 1985). In all these tasks, previous exposure to an item facilitates subsequent detection or production of the same item. For example, reading a word in a study list improves the probability of its correct identification when it is subsequently presented in a tachistoscopic identification task. A directed search for specific episodic representation of the word is not required, since there is no need for explicit remembering of the earlier presentation; nevertheless, enhancement of performance gives implicit evidence of some encoding in memory. This improvement in perceptual fluency due to the repetition of exposure is often referred to as the repetition (Logan, 1985), identity (Dark, Johnston, Myles-

Worsley & Farah, 1985), or direct (Tulving *et al.*, 1982) priming effect. Hereafter the terms of explicit and implicit memory (Graf & Schacter, 1985) will be used to distinguish between expressions of memory which are revealed respectively through recall or recognition tests, and those related to direct priming phenomena.

Two general lines of arguments have been advanced to support the idea that the above distinction reflects a major subdivision of the memory systems.

The first derives from the empirical independence between performances observed on conventional memory tests on the one hand, and tests sensitive to the direct priming effect on the other. Independence may be shown with items used as the unit of analysis. Items are presented for study, then a traditional memory task, and a test designed to assess the priming effect, are successively administered. In these conditions, stochastic independence between remembered and primed items is the most frequent result. This independence has been shown to exist between recognition memory and performance on a tachistoscopic identification task (Jacoby & Witherspoon, 1982), a word fragment completion test (Light, Singh & Capps, 1986; Tulving *et al.*, 1982), or the speed of reading (Kolers, 1976), among others. Independence may also be inferred from a comparison across subjects. The most compelling evidence comes from comparisons between amnesics and control subjects. Amnesic patients show a severe impairment in memory capacity as assessed by conventional recall or recognition memory tests. However, they exhibit a normal repetition priming effect when given a word completion test (e.g. Graf, Squire & Mandler, 1984), a reading task (Moscovitch, Winocur & McLachlan, 1986), or when asked to spell homophones (Jacoby & Witherspoon, 1982). A similar dissociation has been observed when comparing young and older adults in word completion and perceptual identification tasks (Light & Singh, 1987).

The second kind of data supporting the assertion that explicit and implicit memories evolve from separate systems comes from their differential sensitivity to several experimental variables. One of the most thoroughly investigated variables is the level or type of initial processing devoted to the to-be-learned materials. The dependence of the traditional retrieval tests on the level, depth, or amount of item encoding has been a recurrent theme in memory literature since the original formulation of the levels of processing framework by Craik & Lockhart (1972) and the revised versions of the model (e.g. Anderson & Reder, 1979; Jacoby & Craik, 1979), and this point needs no further documentation here. On the other hand, several experiments have demonstrated that manipulations intended to change the level of processing during initial encoding have no effect upon subsequent measures of implicit memory. For example, in Graf & Mandler's (1984) first experiment, the tasks assigned to the groups were either semantic (such as rating of concreteness) or perceptual in nature (such as judging whether two adjacent words had any vowels in common). These manipulations were effective on subsequent recall and recognition tasks, but performances on a word fragment completion test were not affected by the variation in processing activities. Although controversial evidence may be found (Forster & Davis, 1984; Logan, 1985; Oliphant, 1983), findings lending support to the Graf & Mandler (1984) experiments have been reported in Carrol *et al.* (1985), Eich (1984), Graf, Mandler & Haden (1982), Graf *et al.* (1984), Jacoby & Dallas (1981), and Ohta (1984). The Dark *et al.* (1985) experiments confirm this point: the direct priming effect remains intact when the stimulus is displayed for a very brief study time precluding any later recognition.

Several other variables also affect explicit and implicit memory differently, such as the number of associates generated to the studied words (Nelson, Canas, Bajo & Keelean, 1987), changes in modality of presentation between study and test sessions (e.g. Roediger & Blaxton, 1987) and the retention interval (e.g. Komatsu, 1985; Tulving *et al.*, 1982; for a review, see Schacter, 1987).

There are however some exceptions. For example, Jacoby & Dallas (1981) claim that the spacing between repetitions exerts parallel effects on remembering and priming. In the experimental setting devised for exploring the effect of spacing, a list containing items occurring twice or more is presented for study. Repetitions of the *massed* items occupy adjacent list positions. One or more events intervene between successive occurrences of the *spaced* items. As a rule, performance obtained in subsequent free recall, cued recall, or recognition tests, is better for spaced than for massed items (for a review, see Crowder, 1976, pp. 273–314; Hintzman, 1974, 1976, pp. 65–80).

This alleged similar positive effect of spaced practice on implicit memory tests is somewhat puzzling. Indeed, most of the theoretical accounts of the spaced-practice effect emphasize that the influence of spacing between repetitions on later retention is mediated by its action upon the level, depth, or effectiveness of processing initially allocated to items (for a review, see Perruchet, 1987). If, as suggested by the aforementioned literature, the improvement in processing produced by spacing is useless when tasks tap implicit memory operations, the spaced-practice effect should fail to occur in these latter tasks.

This line of reasoning suggests that the empirical evidence supporting the effect of spacing on implicit memory should be examined in greater detail. In the two relevant experiments (referred to as 4*a* and 4*b*) reported by Jacoby & Dallas (1981), words presented twice under massed (lag = 0 item) or spaced (lag = 15 items) conditions were subsequently displayed for a test of tachistoscopic identification. The probability of identification was indeed higher for spaced than for massed words: respective values are 0.45 and 0.58 in Expt 4*a*, 0.71 and 0.76 in Expt 4*b*.

These results nevertheless call for several cautionary comments. First of all, the magnitude of the reported differences was low, and only reached significance in the first study. These data contrast surprisingly with the usual strong and pervasive effect for recall or recognition. Furthermore, the resulting pattern may be accounted for by factors other than spacing. In list-learning experiments, the massed/spaced status of any item is correlated to some extent with its serial position: spaced items tend to be closer to the early and late list position than massed items (e.g. Crowder, 1976, pp. 274–275). Dissociating the spaced-practice effect from primacy and recency effects requires either the running of special data analysis methods, such as those Glenberg (1974) used, or at least building precautionary measures into the experimental design such as the introduction of buffer items at the beginning and at the end of the study list. Inserting a distractor task between study and test is also commonly used to suppress, or at least lower the strength of the recency effect (Hintzman, 1974). All these desirable features are lacking in the Jacoby & Dallas (1981) experiments.

The following four experiments were aimed at testing for a spaced-practice effect in implicit memory as assessed by a perceptual clarification procedure, with a design that eliminates the drawbacks of the Jacoby & Dallas experiments.

In addition, the experiments investigated a still undocumented question concerning the existence of a lag effect in implicit memory. The lag effect refers to the enhancement in long-term retention often observed on standard memory tasks when the number of intervening events between two successive occurrences of spaced items is increased (e.g. Melton, 1967, 1970). Feustel, Shiffrin & Salasoo (1983) claim that they observed a lag effect in a perceptual clarification procedure; however, it is worth noting that in their report they refer unconventionally to the (negative) effect on memory performance of the lag intervening between the item exposures and the test, and not to the (positive) effect of the lag separating two exposures of the same item, which is of interest here.

General method

The experiments described below have a number of features in common. These will be described first.

Subjects were university students majoring in psychology. They reported normal or corrected-to-normal vision, and were native French speakers.

Subjects were tested individually. They were seated facing a CRT screen in a dimly lit room separated from the apparatus room. The experimental sessions consisted of three phases (study, distractor and test), which were run in immediate succession.

In the *study phase*, a long list of word items was serially displayed. Most of the words were repeated, and repetitions were either massed or spaced.

In the *distractor phase*, subjects were given a rehearsal blocking task, whose nature and length varied across experiments.

In the *test phase*, subjects were given either explicit or implicit memory tasks, or both. Subjects submitted to both kinds of tasks viewed different words on each. Explicit memory tasks, either recall or recognition, were administered to ensure that the study phase would elicit the common spaced-practice and lag effects on a standard memory test.

The test of implicit memory used throughout the four experiments is similar in nature to the tests used by Dark *et al.* (1985) and Feustel *et al.* (1983) and, more specifically, to the 'continuous threshold latency identification' version of these tests. On each trial, a word appears embedded within a mask which vanishes gradually (the visual signal-to-noise ratio was progressively increased). As soon as the word became clear enough to be identified, the subject pressed a key which triggered the return of the complete mask, and simultaneously said the word aloud. Both the latency of the key-pressing responses, and the correctness of verbal identifications were recorded.

The same pool of words served for all subjects. They were low frequency, five-letter words, without diacritical marks, and bore no particular semantic relation to one another. Assignment of words to experimental conditions was made randomly for each subject. Order of presentation, including the position of the massed and spaced items within the list, was also randomized for each subject.

The entire experiment was controlled by an Apple IIe microcomputer. In both the study and the test phases, the words were displayed via the standard video unit of the microcomputer, which was placed facing the subject at a distance of 80 cm. The characters were upper-case roman letters, thicker than the standard upper-case characters of the microcomputer. The vertical and horizontal visual angles subtended were approximately 0.36° and 3° for an entire word; letters subtended between 0.36° (for I) and 0.57° (for M) horizontally. These words were enclosed within a visual matrix of 7×56, i.e. 392 pixels. The masks used in the perceptual clarification procedure were formed by superimposing 130 dots in this matrix such that a point falling inside the boundaries of a letter (normally on) was off, and a point falling outside a letter (normally off) was on. The dot coordinates were randomized and varied for each word and each subject. The fading-in was obtained via a point-by-point on/off inversion of the mask, in a random order. It was normally interrupted by the subject's response; if not, its complete duration was 3200 ms. It is worth noting that the technique for masking differed from the methods used in the above mentioned studies, but in a way which presumably did not affect the nature of the task for the subjects.

Latency of identification was recorded to the nearest ms; latencies longer than 3500 ms were discarded and replaced by the mean latency for the subject.

As is the most frequent procedure, non-transformed latency data were subjected to ANOVA (Perruchet, 1982), despite a slight skewness of distributions. The errors in some cases generated J-shaped distributions, and non-parametric statistical tests were used (mainly the Wilcoxon matched-pairs signed-ranks test, hereafter denoted as t). Nevertheless, F tests were also performed for error probability and yielded identical conclusions.

Experiment 1

Method

Subjects. Thirty-two second-year university students served as subjects as partial fulfilment of a course requirement.

Stimuli and procedure. Words assigned to the different experimental conditions were randomly drawn, for each subject, from a pool of 100 low-frequency words (less than 6.4 occurrences per million, according to Gougenheim, Michéa, Rivenc & Sauvageot, 1956).

Subjects were randomly assigned to one priming and one recognition group, each having 16 subjects. Study and distractor phases were identical for both groups.

In the study phase, subjects were shown a list of 70 items. Each item was displayed for 500 ms, then the screen was cleared for 1500 ms before the appearance of the next item. Subjects were instructed to read the words aloud. The reading task was given in order to check the correctness of word identification. The percentage of errors was almost nil, and errors were discarded from the data analysis.

Twenty-two words were presented once. Twelve were used as buffers at the beginning (6) and at the end (6) of the list, and 10 were used to fill the empty spaces in the list. The remaining 48 items consisted of 24 words which were presented twice. The lags between repetitions were 0, 2, 4, or 8 items (6 words were allotted to each lag). The lists were constructed according to an algorithm similar to the one described by Young (1966), in which a word and a spacing are randomly drawn, and then fitted into the list as early as possible. Bellezza, Winkler & Andrasik (1975) have shown that this procedure may lead to placing the spaced items earlier in the list than massed items. In order to eliminate this bias, the search for placement began alternatively at the beginning or at the end of the list.

In the distractor phase, the experimenter read sequences of digits of increasing length, and the subjects had to repeat them in the same order. This task lasted about five minutes. Results regarding numerical memory span will not be discussed here.

In the test phase, 100 words were presented. They consisted of eight training words, followed by 46 new words and the 46 different words from the study list, which were randomly intermixed.

For the priming group, subjects were asked to react by pressing a key as soon as they were able to identify the masked word. Subjects also had to say the word aloud. Responses were checked for accuracy by the experimenter. Depending on correctness, the words 'correct' or 'error' appeared on the screen instead of the mask for 3300 ms. Then the screen was cleared, and remained blank until the next trial, 4200 ms later. Subjects were initially instructed to try as far as possible to keep the percentage of errors less than 10 per cent.

For the recognition group, words were normally displayed on the screen for 3 s. The subjects' task was to press a key when the word was recognized as part of the study list. Then the word 'correct' or 'error' (depending on response correctness) appeared on the screen instead of the word for 1500 ms. Latency of the (eventual) responses was recorded to the nearest ms. The screen was cleared and the next trial began 1500 ms later.

Results and discussion

The main results are summarized in Table 1.

Recognition scores. Overall, 74.86 per cent of words from the study list were correctly recognized. The percentage of distractor words which were incorrectly recognized as having been in the study list (false alarms) was 10.73.

Single-presented words were less frequently recognized than twice-presented words (62.5 vs. 82 per cent, $t = 0$, $n = 16$, $P < 0.01$), but latency of recognition did not differ (978 vs. 966 ms, $F < 1$).

The same tendencies emerged with regard to the spaced-practice effect when the probability and the latency of recognition were examined. Spaced items (lags of 2, 4, and 8) were more often (84.4 vs. 75 per cent, $t = 21.5$, $n = 16$, $P < 0.05$) and more quickly (935 ms vs. 1060 ms, $F = 5.40$, d.f. $= 1, 15$, $P < 0.05$) recognized than massed items (lag of 0). This result replicates the conventional spaced-practice effect. On the other hand, there was virtually no lag effect, either in terms of recognition probability (a Friedman two-way analysis of variance gave $\chi_r^2 = 0.875$, d.f. $= 2$, n.s.) or in terms of latencies ($F < 1$, d.f. $= 2, 30$).

Priming scores. The total percentage of identification errors was 13.04 for the new words, and 7.61 for the old words ($t = 13$, $n = 16$, $P < 0.01$). These trials were eliminated from all subsequent identification time analyses. In comparison to new words, old words were identified at shorter latencies. The mean difference reached 168 ms ($F = 33.25$, d.f. $= 1, 15$, $P < 0.001$). These results are characteristic of the standard repetition priming effect.

Subjects were slower (2707 ms vs. 2627 ms) in identifying massed than spaced items. However, the 80 ms difference did not reach significance ($F = 1.88$, d.f. $= 1, 15$, $P = 0.19$).

Experiment 2 was intended to investigate further the effect of spaced practice in implicit memory, under conditions conducive to increasing the amount of spaced-practice effect upon conventional indices of explicit memory. Although the effect was significant in the recognition group in Expt 1 for both accuracy and latency,

Table 1. Results of Expt 1. Performances in test phase of control (recognition) and experimental (perceptual clarification) groups are shown on the right, facing the conditions of the study phase summarized on the left; latency data (in ms) are conditionalized on correct responses

		Test phase			
		Recognition		Perceptual clarification	
Study phase					
No. prior exposures	Lag between repetitions	% of correct recognitions	Mean latency of recognition	% of correct identifications	Mean latency of identification
0	—	—	—	87.0	2818 (SE = 31.9)
1	—	62.5	978 (SE = 41.5)	91.9	2651 (SE = 44.1)
2	0	75.0	1060 (SE = 61.2)	95.8	2707 (SE = 51.9)
2	2	83.3	922 (SE = 48)	93.7	2594 (SE = 45)
2	4	87.5	938 (SE = 60.9)	91.7	2667 (SE = 56.5)
2	8	82.3	945 (SE = 51.5)	93.7	2621 (SE = 58.7)

moderate differences appeared. This result may be due to the fact that items were displayed for a very short interval. Waugh (1970) and Wenger (1979) have shown that brief exposure durations may prevent the spacing effect from appearing.

In Expt 2, duration of word exposure in the study phase was increased, and subjects were asked to note if a word had been previously presented. This task was superimposed on the reading task in order to ensure that sufficient attention was being devoted to words. Since it is likely that these changes facilitated learning, and that recognition performances in Expt 1 were already close to ceiling, control subjects were administered a (more difficult) free recall test.

The number of the lags was increased from 3 to 5, in order to explore a larger parameter range for the lag effect. Additional changes concerned the proportion of old and new words presented in the priming session. There were only 10 per cent new words (instead of 50 per cent in Expt 1). This feature was designed to test whether the Jacoby & Dallas positive results could be attributed to their use of a low proportion of new words (25 per cent). The rationale for this hypothesis is that subjects may make use of the explicit remembering of the study list in performing the implicit memory task when they discover that some of the words have been previously exposed (Schacter, 1987). For example, subjects may occasionally select a word from several plausible responses (generated from the available cues) on the basis of their earlier presentation within the study list. If such is the case, then the convergence of behavioural laws from presumably implicit and explicit memory tasks becomes a trivial finding. Although this potential drawback is always present in implicit memory research, its likelihood seems to increase when the proportion of new words present in the test list decreases.

Experiment 2

Method

Subjects. Thirty-two students from the same pool as Expt 1 served as subjects.

Stimuli and procedure. In the study phase, subjects were shown a list of 120 words. Eight words were used as a primacy buffer, eight words were used as a recency buffer, and eight words were used to fill the empty spaces in the list. The remaining 96 items consisted of 48 different words which were repeated twice. The lags between repetitions were 0, 2, 4, 8, 16, and 32 items (eight words per lag). Each word was displayed for 2500 ms, then the screen was cleared for 500 ms before the next trial. Subjects were instructed to say 'yes' when they recognized a word that had already been exposed. They were told to remain silent when the words were judged to be new.

The distractor phase was identical to the one used in Expt 1.

In the test phase, subjects in the priming group were shown a list of 100 words. These consisted of 20 training words, followed by a random intermix of eight new words and the 72 different words presented in the study phase. Subjects were asked to press a key and pronounce each word as soon as they could identify it, as in Expt 1. Subjects in the control group received a blank page for a free recall test, with instructions to write the words that had been presented in any order. Four minutes were allowed for recall.

Results and discussion

Performances on recognition for the second occurrence of repeated words during the study phase provided an opportunity to test the homogeneity of the priming and recall groups. The total number of misses was 46 and 55 respectively (chi square = 0.86, d.f. = 1, n.s.). Therefore, both groups were considered to be homogeneous, at least as regards their short-term recognition performances.

Results for the test phase are summarized in Table 2.

Recall scores. Subjects recalled 15.19 per cent of the study list words.

Single-presented words were recalled less often than twice-presented words (7 vs. 18.2 per cent, $t = 11$, $n = 16$, $P < 0.01$).

Spacing between repetitions had a marked effect. Subjects recalled more than twice the number of items under spaced than under massed conditions (20 vs. 9.4 per cent, $t = 2.5$, $n = 16$, $P < 0.01$). Although recall of spaced items did not significantly differ as a function of overall lags, lag 2 elicited poorer performances than the other lags ($t = 7.5$, $n = 16$, $P < 0.01$).

Priming scores. Performances again exhibited a repetition priming effect. The total percentage of identification errors was 11.7 for the new words, and 6.4 for the old words ($t = 37.5$, $n = 16$, n.s.); error trials were eliminated from subsequent identification time analysis. Old words were identified 205 ms before new words ($F = 11.43$, d.f. = 1, 15, $P < 0.005$).

The only other significant difference concerned the effect of repetitions: a single earlier presentation elicited longer latencies of identification than the two earlier presentations (2729 ms vs. 2605 ms, $F = 6.77$, d.f. = 1, 15, $P < 0.025$).

Spaced items were identified only 25 ms before massed items (2626 vs. 2601 ms), and there was no apparent trend in latency when the lag went from 2 to 32 items.

Table 2. Results of Expt 2. Performances in test phase of control (recall) and experimental (perceptual clarification) groups are shown on the right, facing the conditions of the study phase summarized on the left; latency data (in ms) are conditionalized on correct identifications

Study phase		Test phase		
		Recall	Perceptual clarification	
No. prior exposures	Lag between repetitions	% of recalled words	% of correct identifications	Mean latency of identification
0	—	—	88.3	2835 (SE = 68.7)
1	—	7.0	95.3	2729 (SE = 51.6)
2	0	9.4	96.9	2626 (SE = 48.6)
2	2	14.1	94.5	2575 (SE = 37.6)
2	4	22.7	94.5	2637 (SE = 63.7)
2	8	23.4	92.2	2580 (SE = 60.4)
2	16	18.0	93.0	2609 (SE = 49.3)
2	32	21.9	91.4	2606 (SE = 57.5)

These findings suggest that the low proportion of new words in the priming session is not a crucial point: although non-significant in both cases, the effect of spacing was stronger in Expt 1, which used 50 per cent new words, than in Expt 2, which used only 10 per cent new words.

The following experiments pursued the exploration of the spacing effect in implicit memory, with slight changes in procedure. Changes mainly affected the instructions. First, conventional instructions for intentional learning were given to subjects at the start of the study phase. Secondly, instructions in the priming phase emphasized speed of responding at the expense of accuracy. The reasons for this latter change stem from the finding in the first two experiments indicating a correlative increase of error rate and spacing. Although far from statistical significance, this feature is potentially disturbing, since the slight difference in latency favouring the spaced-practice effect could be accounted for in terms of a speed–accuracy trade-off. In both cases, the total number of errors was too low to allow for a reliable analysis. Instructions emphasizing speed of responding were expected to increase the rate of identification errors and thus to facilitate subsequent analysis of error patterns.

Experiment 3

Method

Subjects. Eighteen paid students from psychology classes served as subjects.

Stimuli and procedure. Sixty words were selected in addition to the pool of words used in Expts 1 and 2, according to the same criteria except for frequency occurrence: selection had to be extended to slightly more frequent words than previously used. The 160 selected words had a frequency of less than 12.8 occurrences per million, according to Gougenheim *et al.* (1956).

In contrast to the previous experiments, the nature of the memory test (explicit vs. implicit) was designed as a within-subject factor. This feature implied the use of a recognition task as a control situation, in order to avoid sequential interference which would be elicited by a free recall task. Consequently, the experimental session consisted of four phases: study, distractor, priming and recognition. The order of the last two phases was counterbalanced across subjects, such that half had recognition prior to priming and half had the reverse.

In the *study phase*, subjects were shown a list of 130 items. Each item was displayed for 2 s, then the screen was cleared for 1500 ms before the appearance of the next item. Subjects were instructed to read each word as it was presented, and to remember the words for a later recognition test. Thirty-four words were presented once. Ten words were used as buffers at the beginning and at the end of the list, and 24 words were used to fill the empty spaces in the list. The remaining 96 items consisted of 48 words which were presented twice, at lag of 0, 2, or 16 items (16 words were allotted to each lag). The same algorithm as in prior experiments was used, with a supplementary restriction, designed to avoid the repetition of identical sequences of words: the first appearance of a spaced item did not occur immediately after the first appearance of another item assigned to the same lag.

The *distractor phase* consisted of a tracking task lasting about 20 minutes. Subjects had to exert a continuous movement on a pump-like lever, in order to keep a mobile segment as near as possible to a target line displayed on the screen.

In both the *recognition phase* and the *priming phase*, 72 words were presented. There was no overlap between the two lists. Each list consisted of 36 new words and 36 words from the study list, which were randomly intermixed. The 36 old words were made up of 12 once-presented words, and eight twice-presented words for each of the three lags. Six additional words were presented at the beginning of the priming test for training. The procedure used for the recognition test was the same as described in Expt 1. The procedure for priming differed from the one used in Expts 1 and 2 on two points. First, the time course of the experiment was speeded up. The rate of word clarification was unchanged, but the indicator of correctness as well as the subsequent blank interval were each only 1500 ms long. These modifications were aimed at matching the temporal parameters of the priming and recognition tasks. Secondly, instructions stressed speed at the expense of accuracy (subjects were instructed to react as fast as possible, without worrying about errors).

Results and discussion

Performances did not differ in any significant or systematic way as a function of testing order of the recognition and priming tests. Consequently, further analyses collapsed the data across this factor. The main results are shown in Table 3.

Recognition scores. On the whole, 78.85 per cent of the words were correctly recognized. The mean percentage of false alarms was 8.95.

Twice-presented words were recognized more often (83.1 vs. 70.4 per cent, $t = 19$, $n = 18$, $P < 0.01$) and more quickly (963 ms vs. 1047 ms, $F = 6.62$, d.f. $= 1, 17$, $P < 0.02$) than once-presented words.

A spaced-practice effect was apparent in terms of frequency of recognition (77.8 per cent under the massed condition, 85.75 per cent under the spaced condition, $t = 21$, $n = 18$, $P < 0.01$). The same tendency emerged for latencies, although the 58 ms difference did not reach significance ($F = 2.75$, d.f. $= 1, 17$, $P = 0.115$).

Analysis of latencies showed a positive effect of lag, which also failed to reach significance: the mean recognition time for lag 16 was 88 ms shorter than the mean recognition time for lag 2 ($F = 3.37$, d.f. $= 1, 17$, $P = 0.084$). Probability of recognition exhibited no corresponding tendency.

Priming scores. Instructions emphasizing speed at the expense of accuracy were partially successful: the mean rate of errors was slightly higher than previously (12.4

Table 3. Results of Expt 3. Performances in recognition and perceptual clarification tasks are shown on the right, facing the conditions in the study phase summarized on the left; latency data (in ms) are conditionalized on correct responses

Study phase		Test phase			
		Recognition		Perceptual clarification	
No. prior exposures	Lag between repetitions	% of correct recognitions	Mean latency of recognition	% of correct identifications	Mean latency of identification
0	—	—	—	87.6	2713 (SE = 24.4)
1	—	70.4	1047 (SE = 37.9)	86.6	2582 (SE = 22.0)
2	0	77.8	1002 (SE = 39.0)	88.2	2624 (SE = 47.1)
2	2	86.1	988 (SE = 34.4)	86.8	2582 (SE = 32.8)
2	16	85.4	900 (SE = 33.4)	89.6	2591 (SE = 39.3)

vs. 10.3 and 6.9 per cent in Expts 1 and 2 respectively). However, the main departure from prior experiments concerned the distribution of errors across conditions. The error rate was nearly constant, since the differences between extreme conditions did not exceed 3 per cent. These results go against the paradoxical tendency which appeared in Expts 1 and 2.

Latencies showed the usual priming effect: old words were identified 120 ms before new words ($F = 38.09$, d.f. = 1, 17, $P < 0.001$). No other differences reached significance. However, as before, spaced words were identified slightly before massed words (38 ms).

A point which warrants consideration concerns the effect of repetitions *per se*, regardless of whether massed or spaced. As in Expt 1, repetitions had no significant effect, and although the probability of correct identification tended to improve as expected when the number of previous exposures to the words went from 1 to 2, speed of identification paradoxically tended to decrease across the same conditions. The problem raised by these data is a crucial one here. Indeed, the issue of the spacing between repetitions becomes meaningless if repetitions *per se* have no effect upon performance.

The present results may be tentatively accounted for by the fact that the experiments were not designed to assess the effect of repetitions. In particular, the once-presented words were added primarily to fill the empty spaces left in the study list when repeated words were assigned to their place; as a consequence, there was a notable disparity between the number of words presented once and twice. Additionally, no words were displayed more than twice. In order to obtain a stronger effect of repetitions than is usually produced, the number of presentations was increased from 2 to 4 in the next experiment. It is worth noting that such a manipulation is known to enhance the spaced-practice effect on explicit memory performances (e.g. Underwood, 1970).

Given that a lag effect was not observed in prior experiments, the lag for all the spaced items was made constant, in order to keep the length of the study list manageable.

Experiment 4

Method

Subjects. Twenty-four third-year university students served as subjects in partial fulfilment of a course requirement.

Stimuli and procedure. The 150 words used in this experiment were drawn from the 160 words used in Expt 3.

The experimental design was patterned after Expt 3, with the nature of the memory task (recognition vs. priming) as a within-subject factor. The order of recognition and priming task was reversed for half of the subjects.

In the *study phase*, subjects were shown a list of 168 items, under the same time constraints as in Expt 3, and with the same instructions. Twenty-four words were presented once, 24 were presented twice, and 24 were presented four times. Half of the repeated words were massed (lag 0) and half were spaced (lag 4). The algorithm used in Expt 2 to generate sequences was modified in order to integrate these new parameters. A supplementary modification was introduced to restrict the probability of repetitions of identical sequences of words: the same sequence of two words could not occur more than twice in the list.

The *distractor phase* consisted of a 20-minute tracking task analogous to the distractor task used in Expt 3.

The *recognition and priming phases* were identical to the ones in Expt 3, except that the 36 old words of each list consisted of 12 once-presented words, six words presented twice at lag 0, six words presented twice at lag 4, six words presented four times at lag 0, and six words presented four times at lag 4.

Results

The running order of the recognition and priming tests elicited no significant differences in performance. Consequently, subsequent analyses collapsed the data across this factor. The main results are summarized in Table 4.

Recognition scores. On the whole, 68.5 per cent of the words were correctly recognized. The mean percentage of false alarms was 10.27.

Words presented four times were recognized more often than twice-presented words (80.9 vs. 64.9 per cent, $t = 21$, $n = 24$, $P < 0.01$), and twice-presented words were recognized more often than once-presented words (64.9 vs. 52.1 per cent, $t = 31$, $n = 24$, $P < 0.01$). Repeated words were recognized 29 ms before once-presented words ($F = 5.52$, d.f. $= 1,23$, $P < 0.02$).

Spaced items were recognized more often than massed items (78.1 vs. 67.7 per cent, $t = 68$, $n = 24$, $P < 0.02$). Spacing improves the frequency of recognition by about 5 per cent for twice-presented words, and by 16 per cent for the words presented four times.

These recognition data replicate the well-established effects on explicit memory of repetition and spacing, including the interaction of both factors.

Priming scores. The total percentage of identification error was 12.2. As in Expt 3, there were only minor and non-significant variations in identification accuracy between experimental conditions.

Table 4. Results of Expt 4. Performances in recognition and perceptual clarification tasks are shown on the right, facing the conditions in the study phase summarized on the left; latency data (in ms) are conditionalized on correct responses

Study phase		Test phase			
		Recognition		Perceptual clarification	
No. prior exposures	Lag between repetitions	% of correct recognitions	Mean latency of recognition	% of correct identifications	Mean latency of identification
0	—	—	—	87.6	2805 (SE = 35.5)
1	—	52.0	750 (SE = 15.6)	85.8	2700 (SE = 36.3)
2	0	61.8	721 (SE = 16.1)	86.8	2693 (SE = 45.5)
2	4	67.3	738 (SE = 19.3)	90.2	2573 (SE = 38.1)
4	0	72.9	712 (SE = 20.6)	91.0	2664 (SE = 49.2)
4	4	88.8	713 (SE = 19.6)	88.2	2618 (SE = 44.6)

Old words were identified 156 ms before the new words ($F = 95.74$, d.f. $= 1, 23$, $P < 0.001$). Among the old words, repeated words were identified before once-presented words. However, the 62.8 ms difference did not reach significance ($F = 3.46$, d.f. $= 1, 23$, $0.05 < P < 0.10$).

A spaced-practice effect was obtained: spaced words were identified 83 ms before massed words ($F = 5.11$, d.f. $= 1, 23$, $P < 0.05$). This positive result cannot be directly attributed to the words which were repeated four times. Mean identification times for items presented two and four times were virtually identical (2633 vs. 2641), and, furthermore, the effect of spacing was stronger for the twice-presented words (120 ms) than for the words presented four times (46 ms).

General conclusion

Recall or recognition were primarily introduced as control tasks to ensure that study conditions would elicit the conventional spaced-practice and lag effects in explicit memory. In all the experiments, spacing improved the performances significantly, both in recall (Expt 2) and in recognition tasks (Expts 1, 3, and 4). However, the lag between spaced repetitions had virtually no effect on the recognition group in Expt 1, and only a weak effect on recall and recognition scores in Expts 2 and 3 respectively. This difficulty in obtaining a strong and reliable lag effect in standard memory tests is by no means an exceptional result (e.g. Underwood, 1983; Wenger, 1979) and does not undermine the validity of other results. However, it makes the concomitant absence of lag effect in word identification devoid of interest. Consequently, the issue of lag effect will receive no further attention here.

In order to provide a better description of priming results, the data from the four experiments were pooled. Table 5 shows the weighted means for accuracy and latency of word identification in the perceptual clarification procedure, as a function of the main experimental conditions.

Table 5. Per cent and latency of correct identifications in the perceptual clarification procedure, as a function of the main experimental conditions; data are pooled on the four experiments

Previous exposures	Number of observations	% of correct identifications	Amount of priming (%)	Mean latency of identification	Amount of priming (ms)
None	2376	87.42	—	2786	—
1	792	88.77	1.35	2662	124
2 or 4 massed	656	91.31	3.89	2660	126
2 or 4 spaced	1504	91.42	4.00	2602	184

A preliminary remark should be made concerning the priming effect *per se*. All four experiments showed a strong priming effect. Overall, words presented at least once were identified 155 ms before new words, and the error rate was reduced by about $\frac{1}{4}$. Thus priming is sufficient to make the effect of any intervening factor apparent.

The main issue addressed in the present paper concerns the effect of spacing. In all the experiments, spaced items were identified before massed items, with differences of 80, 25, 38, and 83 ms in Expts 1, 2, 3, and 4 respectively (differences reached significance only in the last experiment). On average, spacing elicited a gain of 58 ms in identification latency. There was a similar tendency in identification accuracy, but the improvement was negligible.

None of the many factors that were varied across experiments appeared to be linked to the observed amount of spaced-practice effect. Expts 1 and 4, which showed the strongest effect on identification latency, differed on many points: incidental or intentional learning instructions, fast or slow rate of word presentation in the study phase, short or long rehearsal-blocking distractor task, and between-subjects or within-subject design.

General discussion

These four experiments, as well as the two relevant Jacoby & Dallas (1981) studies, all exhibit at least a tendency toward a beneficial effect of spacing in implicit memory tests. The probability of obtaining these results by chance was assessed by adding individual *t*s according to the procedure proposed by Winer (1971), one of the most powerful methods for combining probability (Strube & Miller, 1986). The resulting Z value was 3.09 ($P < 0.005$) (Jacoby & Dallas did not report inferential tests in their Expt 4*b*, and therefore this experiment was not included in the meta-analysis). One objection is that an overall assessment based on published studies, which may tend to selectively present positive findings, is basically flawed. Although this objection cannot be definitely ruled out, it is worth noting that, in current approaches which tend to emphasize the differences between explicit and implicit memory, the lack of spaced-practice effects in implicit memory is potentially a more fruitful and publishable result than the reverse. Thus, it can be argued with a reasonably high degree of certainty that spaced practice exerts a real, although probably slight and fluctuating, effect upon implicit memory performance.

In the introductory section, the likelihood of such a finding was challenged on the basis that implicit memory does not seem to be affected by the variations in the nature or the depth of initial processing (cf. introduction above), which are commonly presented as the cause of the spaced-practice effect in traditional memory tests (for a review, see Perruchet, 1987). This apparent discrepancy may be dispensed with in several fashions.

First of all, the processes underlying the spaced-practice effect may differ according to the explicit or implicit nature of the tests; this hypothesis seems to be logically consistent with the claim that explicit and implicit memory evolve from two separate neurological systems. Alternatively, it may be argued that spacing between repetitions influences both explicit and implicit memory performances via a common process, for instance through its action on a primitive encoding mechanism hard-wired into the memory system. This is consistent with some experimental data from the field of explicit memory, such as the occurrence of a spacing effect in infants (Cornell, 1980) or in adults in incidental learning situations (Shaughnessy, 1976). Of course, this does not necessarily exclude the fact that some forms of memorization strategies human subjects commonly develop in learning situations may also be affected by spacing between repetitions, thereby strengthening the spaced-practice effect as observed in explicit memory tests. The ubiquity and the strength of the empirical effect argues for its overdetermination. These theoretical issues need further specially designed investigations to be clarified.

Finally, a more trivial interpretation may also be examined. Schacter (1987) argues for the possibility that, under usual conditions, explicit memory influences implicit memory performances; for instance, a test cue in an implicit memory task may lead to an involuntary but explicit 'reminding' of the occurrence of a previously studied item, which in turn may influence the subject's response. The correlational study of Perruchet & Baveux (in press) supports the possibility of confusing at least some expression of implicit memory with involuntary explicit memory. If this is the case, experimental variables known to affect explicit memory may be expected to exert parallel effects on implicit memory performances. In particular, a spaced-practice effect in nominally implicit memory tests may in fact be due to a contamination of responding by explicit memory. To rule out this possibility, the above experiments should be replicated under conditions ensuring that initial information is inaccessible explicitly, for instance through tachistoscopic presentation of the study list items.

The present study raises an additional problem concerning the effect of repetitions upon implicit memory performances. A close analysis of the earlier literature shows that the repetition effect in implicit memory, although commonly acknowledged*, has little empirical support. As far as we know, the only relevant experiments were

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* For instance, Johnston & Dark (1986, p. 46) claim that 'identity priming increases up to at least four repetitions of the prime stimulus'. This assessment is grounded on a misinterpretation of Feustel *et al.*'s (1983) results. What is repeated in the Feustel *et al.* procedure is not the prime stimulus *per se*, but the task of perceptual clarification; consequently, the improvement in performance across repetitions may be attributed to the fact that subjects learn to identify the words in degraded conditions. Moreover, the effect may be short-lived, since there is no separation between learning and test trial. If, disregarding these particularities, a comparison is made with the results issued from conventional memory paradigms, one must, at least, shift the values on x-axis one unit: value 2, for example, on Fig. 2, p. 317 in Feustel *et al.*, indicates that subjects only viewed one prior exposure of the item. With this point in mind, it is worth noting that even in the Feustel *et al.* procedure, the real effect of repetitions (several vs. one prior exposure, that is, points 3 and 4 vs. 2 in Feustel *et al.* figures) appears rather small and unstable.

conducted by Jacoby & Dallas (1981, Expts 4*a* and 4*b*) in tachistoscopic identification, and Graf & Mandler (1984, Expt 2) in word completion. In each case, two prior exposures elicited slightly better performances than only one exposure. In Jacoby & Dallas, the percentage of correctly identified items was 54.0 and 61.5 in Expt 4*a*, 73.0 and 73.5 in Expt 4*b* (the authors do not provide inferential tests) with one and two previous exposures, respectively. In Graf & Mandler, the percentage of words correctly completed was 29.3 and 34.5 ($P = 0.055$) in the same conditions. These effects remain severely limited in magnitude. The pattern of data of the present experiments confirms and extends these earlier findings. On the average, repeated words were identified 42 ms before the once-presented words, and with a lesser rate of errors (8.64 vs. 11.23 per cent). However, it should be pointed out that Expts 1 and 3 demonstrated no significant effects, and Expt 4 showed no differences in latency or accuracy of identification for words that were given two or four prior presentations, while frequency of recognition differed dramatically between the same conditions.

Before the full implications of these results can be assessed, the possibility that available data were flawed by some kind of ceiling effects must be ruled out. At least two *a priori* arguments militate against such an artifact. First, the weakness of the effect has been observed in three independent types of tasks: tachistoscopic identification (Jacoby & Dallas, 1981), word completion (Graf & Mandler, 1984), and word identification in a perceptual clarification procedure (*intra*). Secondly, reaction time as used above is not considered to be a dependent variable sensitive to a ceiling effect. However, repetitions may still have an effect, for example, on the persistence of the priming effect over the course of time. If further empirical investigations confirm that the effect of repetitions on implicit memory tests is unstable and remains low in amplitude, this feature may represent one of the most striking departures of implicit memory performances from the traditional laws of learning.

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