The spacing and lag effect in free recall

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ABSTRACT

In list memory experiments, the spacing effect refers to the finding that items that are repeated successively are not remembered as well as items that are separated by at least one different list item. The lag effect refers to the finding that memory for items that are spaced apart improves with increased spacing between repeated items. In an experiment using ten highly practiced subjects, significant spacing and lag effects were observed in free recall of pure lists. Previous failures to observe the spacing effect in pure lists (e.g., Hall, 1992; Waugh, 1970) and the lag effect in general (e.g., Toppino & Gracen, 1985) have lent support to the view that these effects result from rehearsal strategies rather than basic memory processes. The presence of contiguity-related associative retrieval processes in free recall (Kahana, 1996) predicts that spacing and lag effects should be present even in pure lists. Our finding of both a spacing effect (in 10 out of 10 subjects) and a lag effect (in 9 out of 10 subjects) using a pure list design suggests that some factor other than displaced rehearsal plays an important role in producing these effects. Contiguity-related associative processes, perhaps caused by contextual variability, could readily account for these effects.

The spacing and lag effect in free recall

The spacing effect refers to the finding that in many different kinds of memory tasks, items that are spaced apart within a list are better remembered than items that are massed together (see Greene, 1992 for a review). This finding in list memory experiments mirrors a more general finding known as the distributed practice effect. Distributing practice (e.g., 10 one-hour practice sessions instead of 5 two-hour practice sessions) results in faster learning in various procedural tasks in both humans and animals (Woodworth, 1938). In applied educational research it is also known that distributed learning is generally superior to massed learning (see Dempster, 1985 for a review). Despite the long and wide ranging interest in distributed practice and spacing effects, there is still no generally well accepted explanation of these phenomena.

In verbal memory tasks, the spacing effect may result simply from deficient processing of massed items (Hintzman, 1976). In this case, the benefit of spacing should be evident so long as items are not studied successively. However, it has been shown that in free recall, the benefits of spacing items increase with the distance between the repeated items (Melton, 1970; Madigan, 1971). This finding is sometimes referred to as a *lag* effect -- recall improves as the separation (lag) between repeated items is increased. In keeping with the terminology used in this literature, a spacing effect refers to advantage of spaced over massed repetitions. A lag effect refers to the increase in performance with increased separation between repeated elements.

Greene (1989) argued that theories of the spacing effect can be grouped into two general classes: encoding or contextual variability accounts (e.g., Estes, 1955; Glenberg, 1977) and deficient processing accounts (e.g., Hintzman, 1976). According to the contextual variability account, items are coded in relation to some type of information that changes as a function of the separation of the items. This information may reflect the operation of temporal context (e.g., Howard & Kahana, submitted) or context defined by neighboring list items. In either case, separating repeated list items results in a differentiation of their representations. If the repetitions are completely differentiated, the probability of recalling a repeated item should be as high as the probability of recalling either one of two different repeated items. This would account for both the spacing and the lag effect -- the further the items are spaced apart the more they act like two different items.

According to the deficient processing account, the spacing effect results from deficient storage of the massed repetition. This impairment may be a consequence of an automatic habituation-type process, or it may result from a deliberate redistribution of attention away from the repeated item (see Greene, 1989; Hintzman, 1976). Although deficient processing provides a reasonable account of the advantage of spaced over massed items, it does not readily explain the substantial increase in performance often observed with increasing lag between repeated items (e.g., Melton, 1970; Madigan, 1971).

Both Greene (1989) and Kahana and Greene (1993) have found dissociations between the spacing effect in free recall (an uncued memory task) and the spacing effect in cued memory tasks (e.g., frequency judgments, item recognition, implicit memory, etc.). Incidental encoding results in a dramatic reduction or even elimination of the spacing effect in cued memory tasks, but not in free recall (Greene, 1989). In contrast, in categorized lists or lists with high levels of inter-item similarity, the spacing effect is eliminated in free recall but not in cued memory tasks (Kahana & Greene, 1993). These investigators have taken these findings as support for the view that deficient processing is the primary factor responsible for spacing effects in cued memory tasks whereas encoding or contextual variability is the primary factor responsible for spacing effects in free recall.

Although the two-process account of spacing effects is generally consistent with these findings, the experiments conducted by Greene (1989) and Kahana and Greene (1993) used lists containing a mixture of massed, spaced and once presented items. This mixed list approach has been typical of the vast majority of prior research on the spacing effect.

One problem with mixed list studies of the spacing effect is that subjects may differentially rehearse spaced and massed items. In free recall, where the largest spacing effects are observed, rehearsal time is a primary factor predicting performance (Rundus, 1971). Rehearsal also plays a central role in models of free recall memory (e.g., Kahana, 1996; Raaijmakers & Shiffrin, 1981). At early list positions, rehearsal time is distributed among the current list item and the last few items whereas in later list positions, rehearsal time is distributed among items throughout the list (Murdock & Metcalfe, 1978; Modigliani & Hedges, 1987). Spaced words will inherently tend to occupy more early and late list positions. Consequently, it is possible that the advantage of spacing in mixed lists derives from the spaced items having more rehearsal opportunities, and/or occupying more favorable primacy and recency positions (Crowder, 1976). In an effort to counteract these possible confounds, most studies of the spacing effect include once presented items at the beginning and end of the list to act as primacy and recency buffers (e.g., Greene, 1989; Kahana & Greene, 1993).

Failures to find spacing effects in pure list experiments

Evidence that positional effects or differential rehearsal may be responsible for the spacing effect comes from studies that compare performance across pure lists -- lists consisting of either all massed or all spaced items. Waugh (1970) compared performance on lists of massed and once presented words with lists of spaced and once presented words. In a free recall task, there was no difference in overall recall for the massed and spaced lists. However, there was a significant difference in the relative number of repeated to once-presented items recalled in both the spaced and massed lists. In the spaced lists, repeated items were favored over once-presented items, but in the massed lists, once-presented items were favored over repeated items. Based on these results, Waugh (1970) argued that displaced rehearsal was the primary factor in producing spacing effects in mixed lists.

Shaughnessy, Zimmerman and Underwood (1972) obtained additional evidence favoring the displaced rehearsal account of spacing effects in mixed lists. Shaughnessy et al. (1972) gave subjects a self-paced mixed list consisting of half-massed and half-spaced items. They found that subjects spent significantly more time viewing spaced words than massed words. This finding also supports the hypothesis that subjects felt more confident about their ability to later recall massed words than spaced words. If subjects overestimate their memory for massed words they are likely to borrow rehearsal time from massed words and give it to spaced words. This type of rehearsal borrowing is a well known confound in studies of the list-strength effect (see Murdock & Kahana, 1993 for a discussion). In pure lists there can be no such advantage accorded to the spaced items because both massed and spaced items are distributed within their own lists.

Using a pure-list design, Hall (1992) failed to find any advantage of spaced over massed presentation. In his critical third experiment, subjects studied two massed and two spaced lists with words repeated twice in each list. In massed lists, items were repeated successively, whereas in spaced lists, repeated words were separated by 2-4 words. Hall found that in massed lists subjects remembered more items from the first half of the list than from the second half of the list. This is consistent with the view that in the latter half of the list, some of the rehearsal time is reallocated to early list items. Despite this difference between first half and second half list items, overall recall was virtually identical for the two list types (59% for both spaced and massed lists). Based on these results, Hall argued the spacing effect found in mixed list experiments is a consequence of displaced rehearsal rather than some basic memory process. Hall's (1992) findings do not seem consistent with the two-process account of spacing effects (e.g., Greene, 1989; Kahana & Greene, 1993). In particular, failures to find the spacing effect in pure lists suggests that contextual variability may not be a factor in accounting for the spacing effect. Because the lag effect is a natural consequence of contextual variability, failures to observe this effect (e.g., Toppino & Gracen, 1985) raise further questions about the usefulness of the contextual variability construct.

Associative Retrieval Processes in Free Recall

Kahana (1996) introduced a measure of the tendency for subjects to recall items that shared adjacent list positions in adjacent output positions. This measure, referred to as conditional response probability (CRP), relates the probability of recalling item *i + lag* given that item *i* has just been recalled. Positive values of lag indicate forward recalls, whereas negative values indicate backward recalls. Reanalyzing data from a series of large free recall studies, Kahana (1996) found that the CRPs in immediate free recall all exhibit a pronounced advantage for adjacent recalls. In addition, forward adjacent recalls are more likely than backward adjacent recalls. This local asymmetry effect runs counter to the general tendency to begin recalling at the end of the list and move backwards as recall proceeds. Howard and Kahana (submitted) extended this analysis showing that CRPs also exhibit adjacency and asymmetry effects in delayed and continuous distractor free recall.

Although the shape of the CRP in immediate free recall can be explained by a rehearsal based process (Kahana, 1996), it may also result from the retrieval of contextual information that changes slowly during the course of list presentation and is associated with each list item. When this context information is retrieved it tends to serve as a retrieval cue for items in nearby input positions. Howard and Kahana (submitted) showed that these CRP functions are minimally affected by the presence of an inter-item distractor task and hence may reflect the operation of temporal context -- a notion closely related to contextual variability.

The presence of adjacency effects, as reflected in the CRP functions obtained in free recall (Kahana, 1996; Howard & Kahana, submitted), has important consequences for the effects of the spacing of repetitions on recall performance. Consider the case of massed presentation of repeated items in a pure list (e.g., AAAABBBBCCCCDDDDEEEE, where letters of the alphabet denote unique words in a list). Each item in this list has two unique adjacent items (for example, C is adjacent to items B and D). If the items are spaced apart widely in the list (e.g., ABCDEBCADECBDEA…), the number of unique adjacent items increases (in this example, C now has 4 unique items as cues). In general, the further the items are spaced apart, the greater the likelihood that they will have a maximal number of unique adjacent items. The existence of adjacency effects in free recall, as evidenced by the shape of the CRP, thus predict the existence of spacing and lag effects, even in pure lists.

This analysis of free recall together with other evidence implicating contextual variability as a process involved in spacing phenomena (Greene, 1989; Kahana & Greene, 1993), pointed out the need to reexamine the spacing and lag effect in pure lists. A failure of contextual variability accounts of the spacing and lag effect in free recall weakens the claim that contextual variability is a defining factor in free recall -- one that has been used to explain long-term recency effects (e.g., Glenberg & Swanson, 1986) and long-term conditional response probability functions (Howard & Kahana, submitted). The following experiment was conducted to see whether the spacing and lag effect might be observed in a pure list design.

EXPERIMENT

Method

Subjects. Ten undergraduate students at Brandeis University were paid to participate in this multi-session experiment. Subjects completed the entire experiment in nine sessions lasting approximately 30 minutes each. Subjects received $50 upon completion of the experiment.

Procedure. A standard study-test free recall procedure was employed. Lists consisted of 12 words each repeated four times each for a total of 48 words per list. All words were taken from the Toronto Word Pool (Friendly, Franklin, Hoffman, & Rubin, 1982). List presentation was visual and free recall was vocal. Words were presented for 1.5 sec each followed by 0.25 second ISI during which the screen was blank. After list presentation, subjects were given a pattern-matching distractor task. Patterns consisted of 4x4 matrices of filled and empty cells, and subjects were required to produce correct judgments on 20 consecutive pairs of patterns before they could go on to the recall phase. After completing the distractor task, subjects were cued by a tone to recall all of the items they could remember in any order. Two minutes were provided for vocal recall of the list items. A microcomputer controlled all aspects of the experiment including the recording of vocal responses for later scoring and analysis.

There were three list types: massed, spaced short, and spaced long. In the massed condition, each word was repeated four times successively. In the spaced short condition, words had a lag of between three and five items. In the spaced long condition, words had a lag of between seven and ten items.

Across the first three sessions, subjects studied and were tested on nine lists of each type (massed, spaced short, and spaced long), each presented in a random order. After these three sessions, the same 27 lists were represented for study and test in a new random order (words that were in a given list remained in that list, but the order of the lists and the order of items within each list were randomized). This study-test process was repeated a third time for a total of nine experimental sessions divided into three repetition phases. This process of repeatedly testing the subjects on the same lists across sessions was done because of a concern that recall probabilities might be too low given the fast presentation rate and extended distractor task. Our concern was not ultimately realized -- recall probabilities were reasonable in the first phase of the experiment. Additional phases served to replicate the basic result across phases and demonstrate a small incidental learning effect.

Results

Results demonstrated the beneficial effects of spaced repetitions and increasing lag in pure lists. Recall probability was lowest in the massed condition (29%), higher in the spaced short condition (38%), and highest in the spaced long condition (44%). The spacing effect in this pure-list experiment was substantial, with a 50% recall enhancement from the massed to the spaced long condition. Repetition of lists across phases had a small beneficial affect on performance. Performance increased from 35% to 40% across the three phases.

A 3x3 repeated measures ANOVA revealed significant main effects of both list type ($F(106)=55.7$, $MSe=0.017$, $p<0.001$) and repetition phase ($F(106)=11.9$, $MSe=0.010$, $p<0.001$). The interaction between these factors was not statistically significant. A Tukey HSD test revealed that each of the pair-wise differences between overall recall for the three list types was highly reliable. The difference in recall probability for spaced short and massed conditions was highly significant ($t(161)=-8.1$, $p<0.0001$). Even the difference between spaced long and spaced short conditions was highly significant ($t(161)=-5.1$, $p<0.0001$). This latter finding replicates the classic lag effect (Melton, 1970; Madigan, 1971). Figure 1 shows the effect of spacing condition and repetition phase on recall performance.

Insert Figure 1 about here

Analysis of individual subject data shows that these effects were consistent across subjects. Recall in the spaced condition was higher than in the massed condition for every subject in this study (10 out of 10 subjects). The advantage of the spaced long over the spaced short condition was observed in 9 out of 10 subjects.

General Discussion

The experimental study reported here shows that both spacing and lag effects are obtained in pure lists. This finding contrasts with earlier failures to observe spacing effects in pure lists (Hall, 1992) and failures to observe lag effects in general (Toppino & Gracen, 1985). In Hall's experiments, spaced items were repeated only twice and spacing between repetitions was short (2-4 items). This would make it difficult to observe an effect of contextual variability because the contexts of the repeated items are very similar. In our experiment, items were repeated four times and lag was manipulated over a larger range. We can only speculate on why some investigators (e.g., Toppino & Gracen, 1985) have failed to observe a lag effect in free recall when this effect has been observed in many previous studies (e.g., Melton, 1970; Madigan, 1971). Our only comment on the previous literature is that many of the failures to observe spacing and lag effects have had extremely low statistical power and have used naïve subjects. In free recall, naïve subjects often attempt serial recall strategies resulting in unusual serial position curves. This, too, may reduce the effectiveness of contextual variability in retrieval.

The present finding of both spacing and lag effects in pure lists is inconsistent with accounts that are based solely on displaced rehearsal (or deficient processing). Rather, these data are consistent with the idea that spacing items in lists increases the number and/or effectiveness of retrieval cues, either by inter-item associations, or context-to-item associations, where context changes slowly during list presentation. Further research may be able to successfully distinguish between these mechanisms. Initial evidence from studies of free recall under delayed and continuous distractor conditions (Howard & Kahana, submitted), is strongly suggestive of the role of contextual variability in storage and retrieved context in guiding retrieval. Taken together, these findings are consistent with Greene's (1989) two-factor account of spacing effects.

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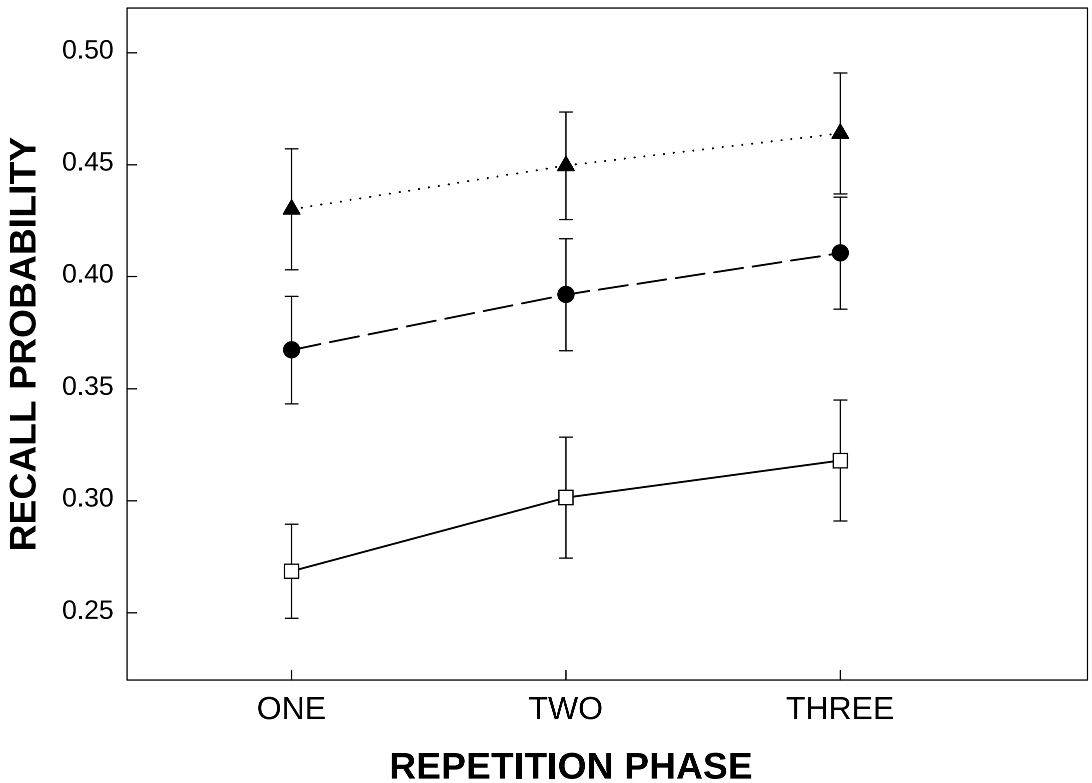
Figure Captions

Figure 1. Effects of the spacing between repeated list items on recall probability in a free recall task. Performance is plotted separately for each of the three pure list types: massed (all repetitions are consecutive), spaced short (an average of 4 items separate each repetition) and spaced long (an average of 8.5 items separate each repetition). All list items were repeated three times. In phase one, subjects studied 27 different lists across 3 sessions. In phase two, the same list materials were re-presented without the subject being informed that the lists consisted of the same items as in phase one. The 27 lists were presented again for study and test in phase three. Error bars are 95% confidence intervals (within-subject) around the mean.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RECALL PROBABILITY
ONE
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