Rote rehearsal and spacing effects in the free recall of pure and mixed lists

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Abstract:

The spacing effect is the commonly observed phenomenon that memory for spaced repetitions is better than memory for massed repetitions. To further investigate the role of rehearsal in spacing effects, three experiments were conducted. With pure lists we found spacing effects in free recall when spacing intervals were relatively long (Experiments 1, 2 and 3), but not when spacing intervals were relatively short (Experiments 2 and 3). In contrast, with mixed lists spacing effects emerged at both short spacing intervals and long spacing intervals (Experiment 3). Additional analyses on the combined pure-list data revealed that the correlation between the primacy advantage and the spacing effect in Quadrants 2 through 4 was positive for all-massed lists and negative for all-spaced lists. This provides some first evidence for the zero-sum nature of the spacing effect in pure lists. The need to incorporate assumptions about rehearsal in theories of spacing is discussed.
Keywords: Spacing effect; Pure lists; Mixed lists; Free recall

Article:

A well-documented finding in the cognitive psychological literature is that repeated items are better remembered when both occurrences are separated by other events or items (i.e., spaced items) than when they are presented in immediate succession (i.e., massed items). This phenomenon has been dubbed the *spacing effect* and it has been demonstrated with diverse populations, under various learning conditions, and in both explicit and implicit memory tasks (for reviews see [Crowder, 1976], [Dempster, 1996], [Hintzman, 1974] and [Hintzman, 1976]). Earlier accounts of the spacing effect have attempted to identify a single mechanism that underlies all spacing effects, but they were ultimately unsuccessful in covering the whole range of empirical data on the spacing effect. Given the shortcomings of these unitary approaches, Greene (1989) suggested that different mechanisms produce the spacing effect in free recall than in cued-memory tasks such as cued-recall, frequency judgment and yes/no recognition. In the present paper, we set out to further examine the spacing effect in free recall tasks.

The spacing effect in free recall has been frequently explained in terms of a contextual variability mechanism (e.g., [Glenberg, 1979], [Madigan, 1969] and [Melton, 1970]). As a class, these theories dictate that contextual change occurring between the first occurrence and the second occurrence of an item is stored automatically with the item's memory trace. Because the number of stored contextual elements is larger for items spaced apart than for massed items, spaced items should have multiple (or stronger) retrieval routes, leading to better memory. More recent versions of the contextual variability account (e.g., [Greene, 1989] and [Raaijmakers, 2003]) propose that the encoding of contextual information requires the retrieval of an item's earlier presentation when this item is encountered again (a process called *study-phase retrieval*). Consequently, the spacing effect in free recall tasks should only emerge for repeated items that have undergone successful study-phase retrieval. The notion that the demonstration of the spacing effect in free recall is conditional upon study-phase retrieval has been supported by several studies (e.g., [Johnston and Uhl, 1976], [Toppino and Bloom, 2002], [Toppino et al., 2002], [Verkoeijen et al., 2004] and [Verkoeijen et al., 2005]).

According to contextual variability theories, spaced items should be recalled better than massed items independent of what proportion of the to-be-learned items are spaced. Therefore, spacing effects should be observed on both *mixed lists* containing some massed items and some spaced items and *pure lists* consisting entirely of massed items or entirely of spaced items. The vast majority of studies on spacing have employed mixed lists and obtained consistently superior recall of spaced items relative to massed items. However, *pure-list* designs are relatively rare in the spacing effect literature and they have produced contradictory outcomes. Underwood (1969, Experiment 2) was the first to compare the free recall of all-massed and all-spaced lists. In accordance with contextual variability theories, he found a spacing effect with pure lists that was comparable to the mixed list spacing effect observed in earlier experiments (Underwood, 1969, Experiments 1 & 2). Underwood (1970) replicated the spacing effect with pure lists using sentences as stimulus materials, but this time the magnitude of the effect turned out to be smaller than with mixed lists.

In opposition to the findings reported by (Underwood, 1969), (Underwood, 1970) and (Waugh, 1970) failed to demonstrate a spacing effect in the free recall of pure lists. Although this discrepancy is puzzling at first sight, it can be resolved if study time differences between the two studies are taken into consideration. In Waugh's experiment, items were repeated zero to eight times, and each item was presented for 1 s whereas in Underwood's first pure-list study (1969) items were repeated three to four times at a 5-s presentation rate. In the second study (Underwood, 1970, Experiment 2) sentences were shown as many as five times at a 10 s per item presentation rate. Thus, in Underwood's studies, some massed words in the first experiment were shown for a period of 20 s, and massed sentences in the second experiment were presented for periods up to 50 s. Hence, massed repetitions could very well have suffered from deficient processing, giving rise to a spacing effect that would not have been observed under more usual circumstances. Hall (1992) underlined the idea that (Underwood, 1969) and (Underwood, 1970) findings had limited generality. Similar to Waugh (1970), he did not observe a spacing effect in his critical Experiment 3 when he gave participants lists of items that contained only massed or only spaced items.

Toppino and Schneider (1999) failed to replicate the null result obtained by Hall (1992). They used a procedure nearly identical to the one in Hall's third experiment, except that items in the spaced lists were separated by two to six items rather than by two to four items. Contrary to Hall's earlier findings, Toppino and Schneider demonstrated a robust spacing effect in the free recall of pure lists. This result was subsequently corroborated by Kahana and Howard (2005). In their study, participants were required to learn fifteen unmixed lists; five lists comprising massed items, five lists comprising moderately spaced items (lags from two to six items), and five lists comprising widely spaced items (lags from six to twenty items). It was shown that moderately spaced items were better recalled than massed items, and that widely spaced items were better recalled than moderately spaced items.

To summarize, the above-described pure-list studies have revealed some contradictory findings, preventing us from drawing firm conclusions about the theoretically important question as to whether the spacing effect occurs in the free recall of pure lists. Recently, Delaney and Knowles (2005) suggested that these inconsistent outcomes can be partially attributed to the fact that pure-list studies (like most mixed-list studies) use intentional learning procedures that blend encoding strategies. In their first experiment, Delaney and Knowles instructed participants to study two all-massed lists and two all-spaced lists, administering a free recall test after each list. The analysis of participants' retrospective reports showed that 78% of the participants started with a shallow rote rehearsal strategy, and that a mere 16% employed a deep relational encoding strategy such as making up a story with the items on a list. However, before reaching List 4, the percentage of participants using a shallow encoding strategy had dropped to 44%, whereas the percentage of participants using a relational encoding strategy grew to 43%. Hence, it appears that people frequently switch from a shallow to a deep encoding strategy after experience studying and being tested on a series of lists (see also Sahakyan, Delaney, & Kelley, 2004). This finding implies that the observed strategy change can influence within-subjects designs in which participants study multiple lists and receive immediate tests, such as in the discussed pure-list studies (i.e, [Hall, 1992], [Kahana and Howard, 2005], [Toppino and Schneider, 1999] and [Waugh, 1970]). This could complicate the interpretation of the results in such designs when strategy interacts with the primary factor under investigation. Indeed, in their first experiment Delaney and Knowles demonstrated a small, non-significant spacing effect for participants who used a shallow encoding strategy during the entire experimental procedure, and a reliable spacing effect for participants who switched to a deep encoding strategy. In their second experiment, they controlled study strategy and again they found a spacing effect for participants using a story mnemonic, but not for participants who employed a rote rehearsal strategy. Taken together, Delaney and Knowles' findings suggest that it is important to control participants' study strategy since pure-list spacing studies can yield inconsistent results when participants are permitted to select their own strategy.

However, the interaction between study strategy and the spacing effect in the free recall of pure lists (Delaney & Knowles, 2005) does not only provide a plausible explanation of the contradictory results of earlier pure-list studies (i.e., [Hall, 1992], [Kahana and Howard, 2005], [Toppino and Schneider, 1999] and [Waugh, 1970]), it also seems to present a problem for contextual variability theories. In more recent versions of this account (e.g., [Greene, 1989] and [Raaijmakers, 2003]), automatically operating mechanisms of contextual variability and study-phase retrieval are thought to underlie the spacing effect in free recall, and therefore, the spacing effect should occur under a rehearsal strategy as well as under a story mnemonic strategy. The absence of a spacing effect following rehearsal learning suggests that much of the data that these theories are based on may need to be re-examined. Given the theoretical importance of Delaney and Knowles' rote-rehearsal results, we reasoned that it would be informative to replicate these outcomes with a different population and with different stimuli in the first experiment of the present study.

Experiment 1

The procedure in Experiment 1 was similar to the one employed in Experiment 2 of Delaney and Knowles (2005). Participants were asked to learn one list of all-massed items and one list of all-spaced items by means of using a rote rehearsal strategy. Following the study of each list, a free recall test was administered. We did not expect free recall to differ between massed and spaced items, consistent with the result reported by Delaney and Knowles (2005).

Methods

Participants

Sixteen first-year psychology students from the Erasmus University Rotterdam, The Netherlands, took part in the experiment in order to fulfill a course requirement. All participants were tested individually.

Materials

Two sets of 32 words were created and frequency counts were obtained from CELEX norms (Baayen, Piepenbrock, & Van Rijn, 1993). Median frequency per million was 61.1 (range 6.9–792) for the words in the first set, and 90.1 (range 7.3–1048.3) for words in the second set. Furthermore, in each set, 16 words referred to things that were man-made (e.g., *church, garden*) and 16 words referred to things that were not man-made (e.g., *rabbit*, *flower*). In each set, the words were used to construct eight versions of a list in which each word appeared twice for a total of 64 presentations. The 64 presentation positions in a list were divided into four groups of eight repetitions (quadrants) and each word was presented equally often in each quadrant of the list. Also, each word occurred equally often as a massed and a spaced repetition. The counterbalancing procedure yielded four lists containing only massed repetitions and four lists containing only spaced repetitions. It should be noted that for each massed list, a corresponding spaced list existed that had all of the same words in the same quadrant. In addition, the order of words on the lists was constrained so that obvious associates were not near one another. For spaced lists, the mean number of words between a repetition's first and second occurrence was 7, with a range of 4–13.

Procedure

Participants were instructed that they were to be presented with two lists of words, and that they had to learn each of these lists by means of rehearsing the words out loud, adding each new word to the set already being rehearsed. Furthermore, they were told that they would receive an unspecified memory test on the words of each list. Because participants talked out loud during the study phase, the experimenter could check whether they complied with the instructions. The two participants who failed to follow the instructions were discarded from the experiment and were replaced.

All participants learned one all-massed and one all-spaced list, with the presentation order of the lists counterbalanced. Each word was shown for 1 s in black print in the center of a computer screen, with a 1-s interstimulus interval. Following the study of the list, participants performed a digit cancellation task for 2 min, and then they were given 3 min to write down as many words from the list as they could remember. Subsequently, after a 2-min break, the identical procedure was conducted for the second list.

Results and discussion

Table 1 depicts the mean proportion of accurate free recall as a function of List Quadrant and Spacing. To analyze the free recall data, a 2 Spacing (massed vs. spaced) × 4 List Quadrant (Quadrants 1–4) repeated measures ANOVA was performed. The criterion for statistical significance was set at $p = .05$ for all subsequent analyses. The main interest of Experiment 1 was whether the absence of a spacing effect, observed by Delaney and Knowles (2005) in a rehearsal strategy condition, could be replicated. Remarkably, however, analysis revealed a clear spacing effect, $F(1, 15) = 8.22$, $MSE = .18$, $p < .05$, $\eta^2 = .35$. Further, there was a marginally significant effect of List Quadrant $F(3, 45) = 2.16$, $MSE = .41$, $p = .06$, $\eta^2 = .15$, indicating that words from the first quadrant were recalled better than words from the other three quadrants. The Spacing × List Quadrant interaction effect turned out to be non-significant $F(3, 45) = .34$, $MSE = .04$, $p = .80$, $\eta^2 = .02$.

Table 1.

Mean Proportion of accurate free recall as a function of List Quadrant and Spacing, Experiment 1

Spacing	**List Quadrant**			
	First	**Second**	**Third**	**Fourth**
Massed	.39 (.04)	.25 (.06)	.23 (.04)	.24 (.06)
Spaced	.39 (.07)	.36 (.05)	.31 (.06)	.31 (.05)

Note. Values in parentheses represent *SE*.

The most striking finding of Experiment 1 is that the results of Delaney and Knowles (2005) were not reproduced and that a spacing effect was observed for rehearsed words. This inconsistency is puzzling because the materials and the procedure used in Experiment 1 of the present study were comparable to those in the second experiment of Delaney and Knowles' study. However, there were notable differences between Experiment 1 and Delaney and Knowles' Experiment 2. For one, the interrepetition interval in the spaced lists was longer in the present experiment (7 words) than in Delaney and Knowles' experiment (4.75 words). This may be relevant given that Kahana and Howard (2005) demonstrated a positive relationship between the length of the interrepetition interval and the spacing effect in pure lists. Also, the presentation time was faster in the present experiment (1 s/item with a 1-s interstimulus interval) than in Delaney and Knowles' experiment (2 s/item with a 1-s interstimulus interval). These differences are important in light of a version of Hall's (1992) displaced rehearsal hypothesis that we (Delaney & Verkoeijen, Submitted for publication) recently proposed to explain the way in which rehearsal affects the spacing effect.

According to our hypothesis, rehearsal serves to magnify the spacing effect in mixed lists, but to diminish it in pure lists. This claim rests on three basic assumptions. First, spacing improves memory. Although a variety of mechanisms have been proposed to explain as to why this occurs (see Dempster, 1996 for an overview), the spacing effect in free recall has been generally attributed to contextual variability (e.g., [Glenberg, 1979], [Greene, 1989], [Madigan, 1969], [Malmberg and Shiffrin, 2005], [Melton, 1970] and [Raaijmakers, 2003]). Contextual variability theories propose that some contextual information is stored with an item, and that items spaced widely apart should therefore have multiple (or stronger) retrieval routes, leading to better memory. Second, rote rehearsal creates functional spacing by distributing practice of an item throughout the list. Third, the influence of distributed practice depends on whether a mixed-list design or a pure-list design is used. Regarding *mixed-list* designs, the distributed rehearsal of earlier-presented items will favor spaced items above massed items because spaced items occur at two or more positions in the list. Hence, the beneficial influence of spacing on memory is amplified on mixed lists because participants rehearse spaced items at the expense of massed items (see [Delaney and Verkoeijen, Submitted for publication] and [Rundus, 1971]). However, in *pure-list* designs, spaced items cannot benefit from rehearsal taken away from massed items. Furthermore, rote rehearsal on all-massed lists will lead to distributed practice of items that were presented in a massed fashion. Therefore, rote rehearsal will convert massed repetitions into functionally spaced presentations (see Modigliani & Hedges, 1987). By contrast, items on all-spaced lists are already repeated in a distributed manner, and as a consequence rehearsal-induced distributed practice will have little, if any, effect on spaced items. In sum, compared to mixed-list designs, pure-list designs reduce the advantage of spaced items relative to massed items, thereby reducing the overall magnitude of the spacing effect.

Our version of Hall's (1992) displaced rehearsal hypothesis does not necessarily predict a null spacing effect on pure lists; the spacing effect in pure-list designs depends on the distribution of rehearsals on the all-massed list compared to the distribution of rehearsals on the all-spaced list. That is, the spacing advantage should disappear when rehearsal produces functional spacing in the all-massed list, which is sufficiently long to yield the same memory performance as the level of spacing in the all-spaced list. By contrast, when the length of the spacing interval on an all-spaced list exceeds the functional spacing on an all-massed list, the spacing effect should emerge.

The above-presented version of the displaced rehearsal hypothesis can explain the discrepancy between the findings of Delaney and Knowles (2005) and those reported in Experiment 1. Given that the presentation rate was 1 s (with a 1-s interstimulus interval) in Experiment 1 of our study and 2 s (with a 1-s interstimulus interval) in Delaney and Knowles' study, it is reasonable to assume that distributed rehearsal in our study was largely limited to recently studied items. Therefore, functional spacing in our all-massed list was probably shorter than in Delaney and Knowles' all-massed list. Furthermore, in Experiment 1 of the present study there were more intervening items between repetitions on the spaced list than in Delaney and Knowles' study. Considering the differences between the experimental procedures, we reasoned that in our study (but not in the Delaney and Knowles study) functional spacing in the all-massed list was too small to yield a similar memory performance as the all-spaced list, leading to a spacing effect in free recall. We conducted a second experiment to test this hypothesis.

Experiment 2

In Experiment 2, participants studied one all-massed list and one all-spaced list. The most important manipulation was directed at the length of the spacing interval in the all-spaced list. We created a condition with very short spacing intervals (short lag) and a condition with long intervals (long lag). Consistent with our version of Hall's (1992) displaced rehearsal hypothesis, a spacing effect should emerge in the long-lag condition, whereas it should be absent in the short-lag condition. That is, in the short-lag condition we expected to replicate the finding reported by Delaney and Knowles (2005).

Methods

Participants

Thirty-two first-year psychology students from the Erasmus University Rotterdam, The Netherlands, took part in the experiment in order to fulfill a course requirement. Participants were only admitted to Experiment 2 if they had not participated in Experiment 1 of the present study. Half of the participants were randomly assigned to the short-lag condition, whereas the other half was assigned to the long-lag condition. All participants were tested individually.

Materials and procedure

The materials and procedure were identical to those used in Experiment 1, with the exception of the length of the interrepetition interval in the all-spaced list. In the long-lag condition, which was an exact copy of Experiment 1, the mean number of words between a repetition's first and second occurrence was 7, with a range of 4–13. By contrast, in the short-lag condition, the mean number of words between a repetition's first and second occurrence was 2.16, with a range of 1–4. It should be noted that the experimental conditions differed only with respect to the spacing interval in the all-spaced list; the same all-massed list was employed in both the short-lag and the long-lag condition. Further, the all-massed list, the all-spaced list in the short-lag condition, and the all-spaced list in the long-lag condition had all of the same words in the same quadrant.

Results and discussion

Table 2 presents the mean proportion of accurate free recall as a function of List Quadrant, Interval and Spacing. A 2 Spacing (massed vs. spaced) × 4 List Quadrant (Quadrants 1–4) × 2 Interval (short-lag vs. long-lag) mixed ANOVA, with repeated measures on the Spacing and the Quadrant factor, was performed to analyze the free recall data. The crucial Spacing × Interval interaction, which is shown in Fig. 1, turned out to be significant, $F(1, 30) = 8.39$, $MSE = .03$, $p < .01$, $\eta^2 = .22$. In the short-lag condition, the analysis failed to demonstrate a spacing effect ($M_{massed} = .32$ vs. $M_{spaced} = .29$), $t(15) = .94$, thus replicating the finding reported by Delaney and Knowles (2005). However, and in line with our prediction, a planned paired *t*-test uncovered a spacing effect in the long-lag condition ($M_{massed} = .29$ vs. $M_{spaced} = .39$) $t(15) = 3.18$, $p < .01$, replicating our Experiment 1.

Table 2.

Mean proportion of accurate free recall as a function of List Quadrant, Interval and Spacing, Experiment 2

Spacing	**List Quadrant**			
	First	**Second**	**Third**	**Fourth**
Short lag				
Massed	.45 (.05)	.36 (.05)	.23 (.04)	.27 (.06)
Spaced	.42 (.05)	.23 (.05)	.20 (.06)	.31 (.07)
Long lag				
Massed	.45 (.05)	.27 (.04)	.19 (.06)	.23 (.05)
Spaced	.42 (.06)	.41 (.06)	.33 (.05)	.39 (.04)

Note. Values in parentheses represent *SE*.

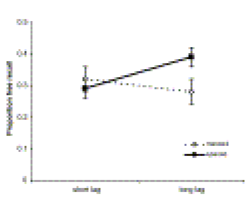
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Fig. 1. Mean proportion of accurate free recall as a function of Spacing and Interval, Experiment 2. Error bars represent ±*SE*.

The remaining results of the omnibus mixed ANOVA revealed that there was neither a main effect of Spacing, $F(1, 30) = 2.12$, $MSE = .03$, $p = .16$, $\eta^2 = .07$, nor of Interval $F < 1$, $\eta^2 = .02$ on free recall performance. By contrast, the main effect of List Quadrant was significant, $F(3, 90) = 12.52$, $MSE = .04$, $p < .001$, $\eta^2 = .29$, indicating that items from the first quadrant were better recalled than items from the other three quadrants. Furthermore, the Interval × List Quadrant interaction $F < 1$, $\eta^2 = .01$, the Spacing × List Quadrant interaction $F(3, 90) = 1.37$, $MSE = .04$, $p = .26$, $\eta^2 = .04$, and the three-way interaction $F(3, 90) = 1.46$, $MSE = .04$, $p = .23$, $\eta^2 = .05$ did not reach the threshold for statistical significance.

The findings of Experiment 2 demonstrate that the length of the interrepetition interval mediates the spacing effect in pure lists when people use a rehearsal study strategy. That is, the spacing effect was shown with long spacing intervals, but not with short spacing intervals. This pattern of results—which is compatible with our version of the displaced rehearsal hypothesis—suggests that the spacing effect emerges in pure lists when the functional spacing in the all-massed list is shorter than the nominal level of spacing in the all-spaced list. However, we did not obtain think-aloud protocols from the participants in Experiment 2, so we can only provide indirect evidence for our assumption that a fast presentation rate prevents participants from producing long functional spacing intervals.

To address this issue, we compared the present findings with those from another experiment we conducted (i.e., Experiment 1 from Delaney & Verkoeijen, Submitted for publication). This experiment was similar to the long-lag condition in the present Experiment 2 with respect to the number of studied lists (one all-massed list and one all-spaced list), the mean length of the spacing interval (about 7 words), and the employed study strategy. However, the presentation rate in Experiment 1 of Delaney and Verkoeijen was 2-s per word with a 5-s interstimulus interval, compared to a presentation rate of 1-s per word with a 2-s interstimulus interval in Experiment 2. Reasoning from a displaced-rehearsal point of view, such increase of exposure time should lengthen the level of functional spacing in the all-massed list. This in turn is expected to have a negative influence on the magnitude of the spacing effect in pure lists. In line with this prediction, no spacing effect was demonstrated in Experiment 1 of Delaney and Verkoeijen. Thus, the findings from Experiment 1 of Delaney and Verkoeijen in combination with the present findings in Experiment 2 corroborate our version of the displaced rehearsal hypothesis.

Experiment 3

The vast majority of studies on the spacing effect use mixed lists instead of pure lists. Therefore, one purpose of Experiment 3 was to compare the magnitude of the spacing effect on pure lists with the magnitude of the spacing effect on mixed lists for both the short spacing intervals and the long spacing intervals employed in Experiment 2.

On the basis of our version of the displaced rehearsal hypothesis, we expected to reproduce the findings observed in Experiment 2. That is, on pure lists, a spacing effect should be demonstrated with long spacing intervals but not with short spacing intervals. This prediction is based on the assumption that (a) rehearsal transforms massed items on pure lists into functionally spaced repetitions, and (b) a spacing effect is observed in pure-list designs when the spacing level on an all-spaced list exceeds the functional spacing level of items in an all-massed list. However, on mixed lists, rehearsal is redistributed away from massed items to spaced items because spaced items occur at more locations throughout the list than massed items. This process of rehearsal borrowing is independent of the spacing interval, and therefore our displaced rehearsal hypothesis predicts a spacing effect on mixed lists for short spacing intervals and for long spacing intervals. Also, given the two roles of rehearsal in different spacing designs, it follows from our displaced rehearsal hypothesis that free recall of massed items should show a deficit on mixed lists as compared to pure lists, whereas free recall of spaced items should be better on mixed lists than on pure lists.

A second goal of Experiment 3 was to explore the relationship between free recall and serial position in pure lists. By doing so, we could make inferences about the distribution of rehearsal effort across the serial positions in the list. On the basis of the substantial primacy effects (i.e., a free recall advantage of Quadrant 1 items over items from the last three Quadrants) found in Experiments 1 and 2 we hypothesized that rehearsal within a list may be considered a *zero-sum game.* According to this hypothesis, rehearsal directed toward one part of the list will be taken away from other parts of the list. Therefore, rehearsal effort spent on items in Quadrant 1 of a list reduces rehearsal allocated to the items in Quadrant 2 through 4, leading to a primacy advantage in free recall. In case of an all-massed list, such pattern of rehearsal distribution will enhance a spacing effect in the last three quadrants because massed-item recall from Quadrants 2 through 4 is expected to decrease with a larger primacy advantage. By contrast, an increase of the primacy advantage on the all-spaced list will be associated with a decrease of spaced-item free recall from Quadrants 2 through 4, hence diminishing the probability of finding a spacing effect in the last three quadrants. Thus, with respect to all-massed lists, the proposed zero-sum nature of the spacing effect predicts a positive relationship between the magnitude of the primacy effect (i.e., free recall advantage of Quadrant 1 items) and the magnitude of the average spacing effect in Quadrants 2 through 4. Conversely, for all-spaced lists, a negative relationship between the magnitude of the primacy effect and the magnitude of the average spacing effect in Quadrants 2 through 4 is expected.

We assessed these predictions of the zero-sum approach of the spacing effect in Experiment 3.

Methods

Participants

Eighty psychology students from the Erasmus University Rotterdam, The Netherlands, took part in the experiment in order to fulfill a course requirement. Participants were only admitted to Experiment 3 if they had not participated in Experiment 1 or Experiment 2 of the present study. Thirty-two participants were randomly assigned to the mixed-list conditions (N = 16 in the short-lag condition; N = 16 in the long-lag condition). Forty-eight participants were assigned to the pure-list conditions (N = 16 in the short-lag condition; N = 32 in the long-lag condition). All participants were tested individually.

Materials and procedure

The procedure was identical to the procedure used in Experiment 2. Furthermore, for the pure-list conditions (pure short-lag condition and pure long-lag condition), we used the same materials as in Experiment 2. The mixed lists were constructed in such a way that we could compare the same words on the same serial positions on the pure lists and the mixed lists. Specifically, to obtain the mixed lists, we transformed half of the items in each quadrant of the all-massed lists into spaced items. In addition, half of the items in each quadrant of the all-spaced-long lists and in each quadrant of the all-spaced-short lists were transformed into massed items. This procedure yielded 16 mixed lists with an average spacing interval of 2 intervening items (mixed short-lag condition), and 16 mixed lists with an average spacing interval of 7 intervening items (mixed long-lag condition).

Results and discussion

Displaced rehearsal hypothesis of the spacing effect

Table 3 presents the proportion of accurate free recall as a function of List Type, List Quadrant, Spacing, and Interval. We analyzed the free recall data with two 2 List Type (mixed vs. pure) × 4 List Quadrant × 2 Spacing (massed vs. spaced) mixed ANOVAs with List Type as a between-subjects factor and List Quadrant and Spacing as within-subjects factors. The crucial Spacing × List Type interactions are depicted in Fig. 2 (short-lag condition) and Fig. 3 (long-lag condition).

Table 3.

Mean proportion of accurate free recall as a function of List Type, List Quadrant, Interval and Spacing, Experiment 3

List Type	**List Quadrant**			
	First	**Second**	**Third**	**Fourth**
Pure list				
Massed	.41 (.06)	.27 (.06)	.22 (.05)	.27 (.04)

List Type	List Quadrant			
	First	**Second**	**Third**	**Fourth**
Spaced short	.33 (.06)	.22 (.06)	.21 (.05)	.28 (.04)
Mixed list				
Massed	.30 (.04)	.18 (.03)	.24 (.04)	.26 (.04)
Spaced short	.45 (.04)	.34 (.06)	.26 (.05)	.27 (.05)
Pure list				
Massed	.39 (.03)	.23 (.04)	.18 (.03)	.24(.03)
Spaced long	.38 (.04)	.28 (.04)	.29 (.03)	.27(.03)
Mixed list				
Massed	.28 (.04)	.11 (.03)	.19 (.03)	.23 (.04)
Spaced long	.43 (.03)	.21 (.04)	.27 (.05)	.38 (.05)

Note. Values in parentheses represent *SE*.

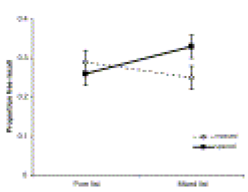
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Fig. 2. Mean proportion of accurate free recall as a function of Spacing and List Type in the short-lag condition, Experiment 3. Error bars represent ±*SE*.

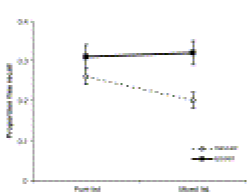
Full-size image (8K)

Fig. 3. Mean proportion of accurate free recall as a function of Spacing and List Type in the long-lag condition, Experiment 3. Error bars represent ±*SE*.

According to our displaced rehearsal hypothesis, with short spacing intervals a spacing effect should emerge in the free recall of mixed lists but not in the free recall of pure lists. Consistent with this prediction a significant Spacing × List Type interaction was obtained in the short-lag condition, $F(1, 30) = 10.03$, $MSE = .02$, $p < .01$, $\eta^2 = .25$. To follow up this interaction effect, we conducted two planned paired *t*-tests. We failed to detect a reliable difference between free recall of all-massed lists ($M = .29$) and all-spaced lists ($M = .26$), $t(15) = 1.05$, replicating the finding we obtained in Experiment 2 with short spacing intervals. However, in mixed lists, memory for massed items ($M = .25$) turned out to be significantly worse than memory for spaced items ($M = .33$), $t(15) = 4.02$, $p < .01$. The remainder of the omnibus ANOVA in the short-lag condition showed a main effect of List Quadrant $F(3, 90) = 6.23$, $MSE = .04$, $p < .01$, $\eta^2 = .17$, indicating that items from the first quadrant were better recalled than items from the other three quadrants. Furthermore, the main effect of Spacing $F(1, 30) = 2.10$, $MSE = .02$, $p = .16$, $\eta^2 = .07$, the Spacing × List Quadrant interaction, the main effect of List Type and the List Type × List Quadrant interaction were not significant *three* *F*'s < 1. The three-way interaction was marginally significant, $F(3, 90) = 2.58$, $MSE = .02$, $p = .06$, $\eta^2 = .08$.

Regarding free recall in the long-lag condition, our displaced rehearsal hypothesis predicts a spacing effect with pure lists as well as with mixed lists. In line with this prediction, analysis revealed an overall spacing effect, $F(1, 46) = 19.83$, $MSE = .03$, $p < .01$, $\eta^2 = .30$. However, the main effect of Spacing was qualified by a significant Spacing × List Type interaction, $F(1, 46) = 4.38$, $MSE = .03$, $p < .05$, $\eta^2 = .09$. Specification of this interaction effect with paired *t*-tests demonstrated that the memory advantage of spaced items relative to massed items was smaller in pure lists ($M_{\text{massed}} = .26$ vs. $M_{\text{spaced}} = .31$; note that this spacing effect replicates our finding from Experiment 2), $t(32) = 2.10$, $p < .05$ than in mixed lists ($M_{\text{massed}} = .20$ vs. $M_{\text{spaced}} = .32$) $t(15) = 4.09$, $p < .01$. The omnibus ANOVA also showed a main effect of List Quadrant, $F(3, 138) = 11.09$, $MSE = .04$, $p < .01$, $\eta^2 = .19$, suggesting that mean free recall performance differed between the quadrants. Furthermore, the main effect of List Type, the two-way interactions and the three-way interaction were not significant *all*, *F*s < 1.92, *all* η^2s < .04.

Our version of Hall's (1992) displaced rehearsal hypothesis predicts that relative to mixed lists, rehearsal will enhance free recall of massed items on pure lists and it will decrease free recall of spaced items on pure lists. As massed items were identical in the short-lag condition and in the long-lag condition, we collapsed our data across these levels of the Interval factor, and performed an independent *t*-test with adjusted degrees of freedom. The outcome of this test confirmed the prediction of our displaced rehearsal hypothesis that massed items from pure lists are better recalled than massed items from mixed lists ($M_{\text{pure}} = .27$ vs. $M_{\text{mixed}} = .22$), $t(72.48) = 2.25$, $p < .05$.

Furthermore, we conducted two separate analyses to compare spaced items in mixed lists and in pure lists. In the short-lag condition, mixed-list spaced items were better recalled ($M = .33$) than pure-list spaced items ($M = .26$) when spacing intervals were short. Although this difference is consistent with our displaced rehearsal hypothesis, it failed to pass the threshold for statistical significance, $t(30) = 1.64$, $p = .10$. Similarly, in the long-lag condition, free recall of mixed-list spaced items (*M* = .32) was not significantly better than free recall of pure-list spaced items (*M* = .31), *t*(46) = .33, *ns*. The latter finding may be attributed to the fact that in comparison to short spacing intervals, long spacing intervals failed to improve free recall of spaced items on mixed lists. This outcome conflicts with the results of some earlier studies that longer spacing intervals yield better memory performance on mixed lists (e.g., [Glenberg, 1977] and [Greene, 1989]).

Because free recall was used as a measure of memory, an alternative interpretation of the above findings is that they reflect a *positive list-strength effect* (e.g., [Ratcliff et al., 1990] and [Tulving and Hastie, 1972]). The positive list-strength effect refers to the finding that weak items (such as massed items) from mixed lists are more poorly remembered than weak items from pure lists and that strong items (such as spaced items) are better remembered when presented in mixed lists than when presented in pure lists. However, we (Delaney & Verkoeijen, Submitted for publication, Experiment 4) observed comparable results with recognition memory using a similar procedure as in Experiment 3 of the present study. This runs counter to the positive-list-strength interpretation because list-strength effects have not been found with recognition tests (e.g., Ratcliff et al., 1990).

Zero-sum nature of the spacing effect

A second issue we examined in Experiment 3 was the proposed zero-sum nature of the spacing effect in pure lists when people used a rote rehearsal study strategy. On one hand, for all-massed lists, we predicted to find a positive relationship between the primacy advantage and the average spacing effect in the last three quadrants. On the other hand, for all-spaced lists, we expected to obtain a negative relationship between the primacy advantage and the spacing effect in the last three quadrants. In order to assess these predictions, we merged the data from Experiments 1 and 2 with the pure-list data of Experiment 3, creating separate data sets for the short-lag conditions and for the long-lag conditions. It was possible to combine the data in this way because the materials and the procedure were identical for the pure lists employed in the three experiments. Subsequently, for each participant the primacy advantage was calculated by subtracting the average proportion of accurate free recall of items from Quadrant 2 through 4 from the proportion accurately recalled Quadrant 1 items. In addition, for each participant the spacing advantage in the last three quadrants was calculated by averaging the spacing advantages in Quadrants 2, 3 and 4.

Table 4 presents the means for the variables massed primacy advantage, spaced primacy advantage, and the spacing effects in Quadrants 2 through 4 as a function of Interval. The correlations between these three variables are displayed in Table 5. In accordance with the zero-sum nature of the spacing effect, we found a positive correlation between the massed primacy advantage and the spacing effect in the last three quadrants, whereas we obtained a negative correlation between the spaced primacy advantage and the spacing effect in the last three quadrants. These correlation patterns were demonstrated with short spacing intervals as well as with long spacing intervals. A *z*-test on the Fisher-transformed correlation coefficients showed that the positive correlation between the massed primacy advantage and the magnitude of the spacing effect in Quadrant 2 through 4 was weaker for short spacing intervals than for long spacing intervals $z = 2.47$, $p < .01$. However, the variance of massed primacy advantage scores was reliably smaller in the short-lag condition than in the long-lag condition $F = 4.16$, $p < .05$. Therefore, the difference between the correlation coefficients may reflect a restriction in range in the short-lag condition. Also, the negative correlation between the spaced primacy advantage and the spacing effect in Quadrant 2 through 4 was stronger in the short-lag condition than in the long-lag condition, $z = 2.43$, $p < .01$.

Table 4.

Means of massed primacy advantage, spaced primacy advantage, and spacing effects in Quadrants 2 through 4 (spacing Q2–4) as a function of Interval

	Interval	
	Short lag	**Long lag**
Massed primacy advantage	.16 (.03)	.18 (.03)
Spaced primacy advantage	.13 (.04)	.08 (.03)
Spacing Q2–4	−.02 (.03)	.09 (.02)

Note. Values in parentheses represent *SE*.

Table 5.

Correlations between massed primacy advantage, spaced primacy advantage, and spacing effects in Quadrants 2 through 4 (spacing Q2–4) as a function of Interval

	1	**2**	**3**
Short lag			
1. Massed primacy advantage	—		
2. Spaced primacy advantage	.10	—	
3. Spacing Q2–4	.36[a]	−.53[b]	—
Long lag			
1. Massed primacy advantage	—		
2. Spaced primacy advantage	−.03	—	

	1	2	3
3. Spacing Q2–4	.60[b]	−.28[a]	—

[a] Correlation is significant at the .05 level (2-tailed).

[b] Correlation is significant at the .01 level (2-tailed).

A reviewer suggested that the above-presented correlations between the primacy advantage and the spacing effect Quadrant 2 through 4 might not be the result of rehearsal effort being distributed across items according to a zero-sum game. Instead, these correlations might have emerged because a larger primacy advantage is associated with a lower overall free recall in *both* massed and spaced lists. To assess this alternative explanation, we calculated four additional correlations. In the short-lag condition, there was neither a significant correlation between the massed primacy advantage and overall massed-list recall $r = .01$, *ns*, nor between the spaced primacy advantage and overall spaced-list recall $r = .01$, *ns*. Further, in the long-lag condition, we found a negative correlation between the massed primacy advantage and overall massed-list recall $r = -.26$, $p < .05$. By contrast, analysis revealed a marginally significant positive correlation between the spaced primacy advantage and overall spaced-list recall $r = .24$, $p = .06$. Considering these four correlations, it seems that there is little evidence for the hypothesis that the associations between the primacy advantage and the spacing effect in Quadrant 2 though 4 are due to a negative correlation between the primacy advantage and overall free recall. Taken together, the results of Experiment 3 support our version of Hall's (1992)displaced rehearsal hypothesis. In line with the predictions based on this hypothesis, we found a spacing effect in the free recall of pure lists when relatively short intervals were used, but not when relatively long intervals were used. Conversely, in the free recall of mixed lists, a spacing effect was demonstrated both in the short-lag condition and in the long-lag condition. Furthermore, consistent with our displaced rehearsal hypothesis, massed items were remembered better when presented in pure lists than when presented in mixed lists. As a final point with respect to Experiment 3, it is worth noting that we obtained some first evidence for the proposed zero-sum nature of the spacing effect in pure lists.

General discussion

A very common task in cognitive psychological research is that participants are required to study a list of words for an upcoming memory test. Most people approach such list-learning task, at least initially, by rehearsing the presented items as often as possible (e.g., [Delaney and Knowles, 2005] and [Sahakyan and Delaney, 2003]). However, in a recent paper Delaney and Knowles (2005) demonstrated that the spacing effect in the free recall of pure lists does not emerge when people employ rote rehearsal study strategies. This finding is important for a number of reasons. First, the spacing effect is extremely robust and it has been found with a variety of testing procedures, stimulus materials and populations (for a recent review, see Dempster, 1996). Consequently, a failure to find the spacing effect in pure lists under rote-rehearsal learning conditions may be theoretically informative. Second, the findings from the spacing effect literature suggest that learning can be enhanced in educationally relevant settings by capitalizing on the beneficial influence of spaced practice. However, Delaney and Knowles' findings show that spacing of information will not improve memory over massing when people employ rote rehearsal strategies, thus limiting the applicability of the spacing effect. Given the theoretical and practical relevance of Delaney and Knowles' findings, we conducted the present series of experiments to further explore to role of rehearsal in the spacing effect.

Experiment 1 aimed at replicating Delaney and Knowless' (2005) results. That is, we expected to find no spacing advantage in the free recall of pure lists. Participants were instructed to employ a rote rehearsal strategy to study one all-massed list and one all-spaced list, receiving a memory test after each list. Compared to the procedure in Delaney and Knowles' critical second experiment, the presentation rate in Experiment 1 was considerably faster (1 s with a 1-s interstimulus interval vs. 2 s with a 1-s interstimulus interval) and the length of the spacing interval was somewhat shorter (7 items vs. 4.75 items). Remarkably, and contrary to what Delaney and Knowles found, Experiment 1 produced a reliable spacing effect.

We interpreted the outcome of Experiment 1 in terms of our version of Hall's (1992) displaced rehearsal theory. According to this hypothesis, rehearsal serves two different functions depending on the type of design that is used. In mixed-list designs, rehearsal distributed learning effort away from massed items towards spaced items, hence increasing the spacing effect. Conversely, in pure-list designs, rehearsal serves to transform nominally massed items into functionally spaced items. Therefore, a spacing effect will only be observed in pure-list designs if the nominal spacing level in the all-spaced list is sufficiently long to yield a better memory performance than the functional spacing in the all-massed list. Experiment 1 used a fast presentation rate, preventing participants from widely distributing massed items throughout the list. As a result, the functional spacing intervals in the all-massed list must have been relatively short. Also, the mean spacing interval in the all-spaced list was relatively long. Consequently, the all-spaced list produced a better memory performance than the functional spacing in the all-massed list, leading to a spacing effect in free recall.

If the above-presented interpretation of our findings from Experiment 1 is correct then the spacing effect should disappear when very short spacing intervals were to be employed. Experiment 2 was performed to test this prediction. The procedure in Experiment 2 was identical to the procedure in Experiment 1. However, half of the participants received an all-spaced list with short spacing intervals (mean spacing of about 2 items; short lag) whereas the other half received an all-spaced list with long spacing intervals (mean spacing of 7 items; long lag). Consistent with our displaced rehearsal hypothesis, the spacing effect was found in the long-lag condition but not in the short-lag condition.

In Experiment 3, pure lists as well as mixed lists were used to further assess our displaced rehearsal hypothesis. Specifically, we propose that in mixed-list designs rehearsal time will be allocated to spaced items at the expense of massed items. Therefore, a spacing effect should be demonstrated in mixed lists with short spacing intervals and in mixed lists with long spacing intervals. Regarding the free recall of pure lists, we expected to replicate the findings from Experiment 2. That is, the spacing effect should interact with the length of the spacing interval. In line with these predictions, the results of Experiment 3 showed a spacing effect with mixed lists in the short-lag condition and in the long-lag condition. However, with pure lists, a spacing effect was demonstrated in the long-lag condition, but not in the short-lag condition. Furthermore, Experiment 3 tested another prediction of our displaced rehearsal hypothesis. That is, according to our hypothesis pure lists should benefit memory for massed items relative to mixed lists. In line with this prediction, massed items were remembered better with pure lists than with mixed lists.

In sum, the findings in the present study corroborate our version of Hall's (1992) displaced rehearsal hypothesis. However, this conclusion should be regarded with some caution. First, although the evidence in favor of the displaced rehearsal hypothesis follows from a combination of the instructions and the employed experimental design, we did not obtain direct measures of rehearsal in the present study. Second, one of the reviewers pointed out that the support for this hypothesis would have been stronger if we had included a control condition in which participants were instructed to rehearse only the most recently presented item. Under such a rehearsal strategy, the displaced rehearsal hypothesis predicts that no spacing effect should emerge in pure-list designs and in mixed-list designs. To alleviate any concern regarding this issue, it is useful to refer to the outcomes of earlier mixed-list research ([Glenberg, 1977] and [Wright and Brelsford, 1978]). Consistent with the prediction of the displaced rehearsal hypothesis, these studies demonstrated that when rehearsal is controlled by instructing participants to repeat only the most recently presented item out loud, the spacing effect in free recall is attenuated or eliminated.

Zero-sum nature of the spacing effect

The last issue explored in the present paper was the distribution of rehearsals in pure lists. We propose that rehearsal within a list can be regarded as a zero-sum system: rehearsal allocated to one part of the list will be taken away from other parts of the list. This implies that extra rehearsal directed at items in Quadrant 1 (the primacy region) will reduce the rehearsal effort spent on Quadrants 2 through 4, leading to a primacy advantage in free recall. If we consider the relationship between the magnitude of the primacy advantage and the mean spacing effect in Quadrants 2 through 4, we can formulate the following predictions on the basis of the proposed zero-sum nature of rehearsal distributions. With all-massed lists, the larger the primacy advantage, the lower the free recall of items from Quadrant 2 through 4 will be, leading to an increase of the spacing effect in Quadrant 2 through 4. Thus, for all-massed list, the zero-sum nature of the spacing effect predicts a positive correlation between the primacy advantage and the spacing effect in Quadrants 2 through 4. By contrast, with all-spaced lists, a decrease of free recall of items from Quadrant 2 through 4 due to an enhanced primacy advantage will have a negative influence on the magnitude of the spacing effect in Quadrants 2 though 4. Hence, for all-spaced lists, the zero-sum nature of the spacing effect predicts a negative correlation between the primacy advantage and the spacing effect in Quadrants 2 through 4. These predictions were supported by the analyses performed on the combined pure-list data from all three experiments. Thus, our findings provide some initial evidence for the zero-sum nature of the spacing effect under rehearsal learning conditions.

Theories of the spacing effect

The present findings have implications for the assessment of theories of the spacing effect. To account for the spacing effect in free recall contextual variability mechanisms have been proposed (e.g., [Glenberg, 1979], [Greene, 1989], [Madigan, 1969], [Malmberg and Shiffrin, 2005], [Melton, 1970] and [Raaijmakers, 2003]), whereas the spacing effect in cued-memory tasks, such as yes–no recognition or frequency judgment, has frequently been explained in terms of a deficient processing mechanism (e.g., [Challis, 1993], [Cuddy and Jacoby, 1982], [Russo et al., 1998], [Russo and Mammarella, 2002] and [Russo et al., 2002]). Experiments that assess these theories are designed with the assumption that the number of repetitions is held constant between massed and spaced items and the spacing of repetitions is controlled for. However, the present study demonstrates that these assumptions are not necessarily true when participants use a rehearsal strategy. That is, due to rehearsal borrowing, spaced items seem to get rehearsed more often than massed items in mixed list. Furthermore, in pure lists displaced rehearsal serves to transform nominally massed items into functionally spaced items. The fact that rehearsal may confound spacing with the number of repetitions (in mixed-list designs) or may obscure the distinction between massed items and spaced items (in pure-list designs) makes it difficult to unearth the influence of non-rehearsal factors, like contextual variability, on the spacing effect. We recommend that researchers take this into account while investigating theoretical non-rehearsal mechanisms underlying the spacing effect.

Conclusion

In memory research, a common task is to ask participants to study a list of words and subsequently to test their memory for these words. Our findings suggest that when participants use a rehearsal strategy to approach such list-learning task, and we know that many of them do (e.g., Delaney & Knowles, 2005), spacing effects in free recall can be interpreted in terms of a version of Hall's (1992) displaced rehearsal theory. With pure lists we demonstrated a spacing effect when spacing intervals were relatively long but not when spacing intervals were relatively short. This result is consistent with the idea that the magnitude of the spacing effect in pure lists depends on the difference between the free recall produced by the *nominal* spacing in all-spaced lists and the free recall produced by the *functional* spacing in all-massed lists. Furthermore, and again in line with our displaced rehearsal hypothesis, it was demonstrated that massed items were better recalled on pure lists than on mixed lists.

In addition to providing evidence for our version of Hall's (1992) displaced rehearsal hypothesis, the present study was the first to examine the distribution of rehearsals in pure lists and its relationship with the spacing effect. We found that the correlation between the primacy advantage and the spacing effect in Quadrant 2 through 4 was positive for all-massed lists and negative for all-spaced lists. These findings support the zero-sum nature of the spacing effect.

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