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Expanded vs. Equal Interval Spaced Retrieval Practice: Exploring Different Schedules of Spacing and Retention Interval in Younger and Older Adults

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ABSTRACT

The present study was designed to help answer several questions regarding the impact of spacing and expanded retrieval on memory performance in younger and older adults. Three expanded/equal interval schedule pairings, matched in average spacing (1-2-3/2-2-2; 1-3-5/3-3-3; and 1-3-8/4-4-4), were compared, and the effect of retention interval on spaced retrieval benefits was examined by comparing performance on a same day test to a test delayed by 24 h. Both age groups showed a learning phase retrieval success advantage for expanded items compared to equal interval items. Only older adults in the same day test condition showed a significant expansion effect in final recall. After a 24-h delay, the final recall advantage for items in the expanded condition was lost in both groups, and in fact these items were at a significant recall *disadvantage* for younger adults. Results indicate that younger and older adults benefit from a rehearsal technique that incorporated any type of spaced retrieval whether it is distributed as an expanding schedule or not. Although we did not find robust advantages for expanded retrieval compared to equal interval practice, there could be certain advantages (such as reinforcement due to high success rates) to using expanded retrieval depending on the ultimate goals of an individual memory training program.

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INTRODUCTION

As the general population grows older, interest is building in the development of techniques designed to improve memory. Indeed, the integrity of memory is important to people across the age span, including college students whose academic success depends on their ability to retrieve information they have been directed to memorize. The current paper focuses on a memory improvement technique called “expanded retrieval,” primarily tested in college-age adults (Balota, Duchek, Sergent-Marshall, & Roediger, 2006; Cull, 2000; Cull, Zechmeister, & Shaughnessy, 1996; Landauer & Bjork, 1978, see Balota, Duchek, & Logan, 2007, for a recent review), and now being applied as a memory rehabilitation technique in Alzheimer’s patients (Camp et al., 1996, 2000; Cherry, Simmons, & Camp, 1999).

Expanded retrieval is based on a robust memory phenomenon known as the spacing effect, in which memory for repeated items is better when repetitions are spaced apart rather than massed together (e.g., Glenberg, 1976; Melton, 1967; for overview, see Crowder, 1976). In expanded retrieval, these repetitions are spaced at ever-increasing intervals, making it necessary to retain the information for longer and longer amounts of time before one attempts to retrieve it. For example, an expansion schedule of 1-3-8 would indicate that an item was retrieved three times, with the first retrieval coming one intervening item after the initial presentation, the second retrieval coming three intervening items after the first retrieval, and the third retrieval coming eight intervening items after the second retrieval. This is in contrast to another type of rehearsal schedule referred to as a uniform or equal interval spacing schedule in which retrievals are evenly spaced with the same number of intervening items between each retrieval (e.g., 4-4-4), even though the total number of intervening items between the two schedules remains the same (see Figure 1).

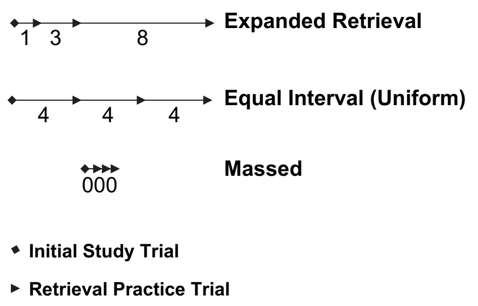


FIGURE 1. A schematic diagram depicting examples of massed, equal interval and expanded retrieval practice schedules. The diamond represents the initial study trial, the line depicts the passing of time and number of intervening items, and each arrow point indicates a retrieval attempt.

Despite the recent use of expanded retrieval, surprisingly little is known about why this procedure may be an effective memory technique. The present study is designed to examine the effectiveness of expanded retrieval schedules compared to uniform spacing schedules in healthy younger and older adults and to investigate the cognitive factors underlying any advantages offered by expanded retrieval.

THE CASE FOR EXPANDED RETRIEVAL: EVIDENCE FOR A SUPERIOR TYPE OF SPACING?

A study by Landauer and Bjork (1978) was the first to demonstrate the benefit of expanded versus uniform retrieval practice for information presented only once (in this case, learning someone's name). In the learning phase (Experiment 1), college-age students were asked to learn a list of first and last names shown on a series of index cards (e.g., John Smith) and then practiced retrieving some items (e.g., John ___) according to various spaced rehearsal patterns. In the subsequent test phase, subjects were given a final cued recall test (John ___).

Results from their Experiment 1 showed that, during both phases of the experiment, memory for items presented in the expanded condition were superior to those presented in the uniform spacing condition, yielding an average 15% increase in performance during the first phase and an 8% increase in the final test phase (interpolated from their Figures 1 and 2). If expanded retrieval is, as Landauer and Bjork suggest, a particularly effective spaced rehearsal technique for long-term retention, this slight drop in performance from the first phase to the final test phase might be considered a bit surprising. Indeed one might have expected the expanded retrieval advantage to increase over time as performance in the equal interval condition declined. In fact it appears that the expanded retrieval advantage in final recall in Landauer and Bjork may stem from the higher likelihood of retrieval success for expanded items during practice – a difference that is apparent from the very first retrieval attempt during learning. Based on such an observation, it is reasonable to wonder whether the expanded retrieval effect is not necessarily one of optimal spacing or time intervals, but rather stems from the higher success rate that such spacing produces. Indeed, Landauer and Bjork suggested that "the expanding pattern is superior because it keeps the probability of a successful test relatively high" (p. 628). A primary question of the current study will be to explore whether the expanded retrieval advantage in final cued recall is due to anything beyond maintaining a retrieval success advantage at larger intervals during learning.

Since the publication of the original Landauer and Bjork (1978) paper, several researchers have sought to extend these findings into more applied settings. Rea and Modigliani (1985) found that third-graders learned multiplication facts and spelling lists better under an expanded retrieval schedule compared to a massed retrieval schedule. In a very different population, Camp and colleagues (Camp et al., 1996, 2000; Cherry et al., 1999) have applied principles of spacing and retrieval practice to remediating memory deficits in Alzheimer's patients. Their particular spaced retrieval technique has been used to successfully train memory for people and objects and even to shape appropriate social behavior in more severely demented Alzheimer's patients (see Camp et al., 2000). Although these studies are intriguing in their applications, they did not involve a comparison of expanded retrieval to other spaced retrieval schedules, which is critical to establishing expansion as a superior form of spaced rehearsal. Recently, Hochhalter, Overmier, Gasper, Bakke, and Holub (2005) published a study comparing the typical spaced retrieval technique of Camp and colleagues to other schedules of rehearsal, including schedules of random intervals, massed intervals, and uniformly distributed intervals. Their specific procedure was quite different from that originally used by Landuaer and Bjork (1978) but the general principle was the same. With a small sample of Alzheimer's patients, Hochhalter et al. (2005) found no significant advantage for the typical spaced expanded retrieval technique compared to other equally spaced schedules of practice.

Using the Landauer and Bjork (1978) procedure in which intervals are comprised of intervening information, only a few studies of expanded retrieval have included appropriate spacing comparisons, namely schedules of practice that are matched in average spacing. Cull et al. (1996) attempted to replicate and extend the findings of Landauer and Bjork (1978) using multiple comparison conditions. The first experiment was a successful replication of Landauer and Bjork, yielding a significant 10% advantage for expanded retrieval (1-5-9 schedule) over uniformly spaced material (5-5-5 schedule) in the final recall test. Cull et al. did not present data from the first phase of the experiment so it is difficult to assess whether the locus of their expanded retrieval effect also stemmed from the success of the initial retrieval attempt. Results from subsequent Experiments 2–4 were equivocal in finding an expanded retrieval advantage (for example, finding a numerical advantage for expanded items that was not statistically significant). In a follow-up study examining the role of feedback and multiple study episodes in producing spaced retrieval effects, Cull (2000) failed to find any evidence that expanded spacing was superior to other forms of distributed practice matched in average spacing.

In a study of face-name learning, Carpenter and DeLosh (2005) compared final recall performance for items practiced on massed, equal interval (3-3-3), and expanded (1-3-5) schedules using a procedure similar to Landauer and Bjork (1978). Contrary to Landauer and Bjork, they found a significant disadvantage (4%) for expanded items compared to equal interval items. In a second experiment which attempted to match the equal interval and expanded conditions on initial retrieval difficulty (comparing a 3-3-3 schedule to a 3-5-7 schedule), they found no significant difference between items practiced on the equal interval and expanded conditions.

Balota et al. (2006) have also recently attempted to replicate the original findings of Landauer and Bjork (1978) in younger adults and extend their findings to healthy older adults and patients with Dementia of the Alzheimer's Type (DAT). It is clear that older adults show a spacing effect that is similar to that seen in younger adults (e.g., Balota, Duchek, & Paullin, 1989; Faust Balota, & Spieler, 2001; Spieler & Balota, 1996). Given the results of Camp and colleagues (Camp et al., 1996, 2000), Balota et al. were interested in examining whether an expanded retrieval schedule offered greater benefits to memory performance in healthy aging and DAT than other spacing schedules. In three experiments of paired-associate learning, Balota et al. did find a robust benefit of spaced retrieval in all groups when comparing memory in the equal interval condition to the massed practice condition. However, there was no advantage of the expanded retrieval schedule compared to a comparably spaced equal interval schedule (1-3-5 vs. 3-3-3).

THEORETICAL BASIS FOR THE EXPANDED RETRIEVAL EFFECT

Little theoretical work has been conducted to address why expanded retrieval may be a superior form of spaced retrieval; however, several explanations have been offered to explain the benefits of spaced practice in general, including retrieval effort, retrieval success, and encoding variability.

Retrieval Effort

The benefits of an expanded distribution of practice compared to other forms of spaced retrieval could be tied to continual increases in retrieval effort, while maintaining retrieval success, as the spacing between retrieval attempts increases (Carpenter & DeLosh, 2005; Cull, 2000). However, others have proposed that expanded retrieval is beneficial for exactly the opposite reason: it requires little cognitive effort compared to retrieval in other spacing schedules (Bjork, 1994; Camp et al., 2000). The notion here is that the very gradual nature of the expansion between retrieval practice attempts encourages success early in practice, which then facilitates later retrieval. Indeed, this assumption is a primary reason that Camp and colleagues have attempted to use this technique with Alzheimer's patients (Camp et al., 2000). The current study is designed to more directly investigate the role of effort in producing expanded retrieval effects by measuring response latencies during retrieval practice.

Retrieval Success

Several studies have consistently found that successful retrieval of an item tends to enhance retention above and beyond an additional study episode (e.g., Carrier & Pashler, 1992; Cull, 2000; Hogan & Kintsch, 1971; Wenger, Thompson, & Bartling, 1980). Expanded retrieval schedules may be superior to other retrieval schedules because they produce a high rate of retrieval success compared to other spaced schedules (Bjork, 1994; Cull, 2000; Landauer & Bjork, 1978; Rea & Modigliani, 1985). As discussed above, data from Landauer and Bjork appear to support this notion. It should be noted, however, that a high probability of retrieval success cannot be the sole source of the expanded retrieval advantage. Massed practice generally produces the highest rate of retrieval success during practice, yet yields fairly dismal long-term retention compared to spaced practice. Thus, conditions that produce successful performance in the short term may not produce the best conditions for longer-term retention (e.g., Pashler, Cepeda, Wixted, & Rohrer, 2005; Schmidt & Bjork 1992). The most effective spaced retrieval schedules, therefore, might be those that balance retrieval effort with retrieval success; namely, an item will optimally benefit from retrieval practice when it requires maximum effort to retrieve without being totally inaccessible (Bjork, 1988). The current study will test a variety of spaced retrieval schedules – expanding and equal interval – to explore this notion of optimally timed retrieval.

Encoding Variability

There is evidence that spaced presentation of repeated items allows for greater encoding variability than massed practice of items, and it is this greater encoding variability that leads to the benefit of spaced presentation (e.g., Balota et al., 1989; Bjork & Allen, 1970; Gartman & Johnson, 1976; Shaughnessy, Zimmerman, & Underwood, 1972; see Crowder, 1976, for overview). In spaced retrieval, the assumption is that the encoding of an item in more than one context will make it more likely that one or more of those contexts will be partly re-instated during later retrieval, thus improving overall retention of the item. During retrieval practice, if the ever-increasing windows of an expanded retrieval schedule allow for greater encoding variability over later retrieval attempts compared to the constant intervals of an equal interval schedule, this may lead to a benefit on final memory tests for expanded items. The current study incorporates practice schedules that use a range of lags (zero to four) to investigate the role of encoding variability in spaced and expanded retrieval effects.

OVERVIEW OF THE PRESENT STUDY

Despite the interest in applying expanded retrieval techniques to various populations with learning difficulties, the preceding review demonstrates that the case for expanded retrieval is not as clear as one might think. Several key issues remain to be explored to better understand the potential benefits of spacing and expanded retrieval in younger and older adults. The present study will explore expanded retrieval in both young and older adults under conditions which allow one to dissociate spacing from expansion. In addition, it will explore the influence of different retrieval practice schedules, retention intervals, and retrieval success on spaced and expanded retrieval effects.

There were several objectives for the current study. A central goal was to investigate potential age-related differences in the benefits of spacing and expanded retrieval. Episodic memory performance typically shows significant declines with age (e.g., Balota, Dolan, & Duchek, 2000; Craik & Jennings, 1992; Light, 1991; Park & Schwartz, 2000). Nonetheless, older adults have shown benefits of spaced repetition that are similar to those observed in younger adults (Balota et al., 1989). It may be that the gradual shaping procedure engendered by an expanded retrieval schedule will be particularly effective for individuals with impairments in episodic memory, such as older adults. Thus, the present study tested both healthy younger and older adults to explore this question.

In exploring spacing and expanded retrieval effects in these groups, a primary issue of interest is the relation between retrieval success in the learning phase of the study and the expanded retrieval effect in final recall. As mentioned above, Landauer and Bjork showed higher rates of retrieval success in the expanded retrieval condition compared to their uniform spacing condition. To our knowledge, only Landauer and Bjork (1978) and Balota et al. (2006) have reported performance during each retrieval event during the learning phase.

In addition, the present study addressed the notion of greater retrieval effort contributing to the expanded retrieval effect. If this is the case, one might expect reaction times for correct retrieval to be greater for the expanded condition than the equal interval condition, especially as the intervals between retrieval attempts become longer. We are unaware of anyone who has measured response latencies during the acquisition phase.

The question of whether a *particular* expansion schedule is optimal for learning and retention – i.e., produces the greatest advantage for memory performance, compared to its equal interval counterpart – remains to be explored. The current study was designed to systematically explore this question. More importantly, this study will examine what is “optimal” as a function of age. There are theoretical reasons to expect that there might be age differences in which expansion schedule offers the greatest memory advantage. Older adults are both slower than younger adults (see Salthouse, 2004) and less likely to encode contextual elements during learning (Balota et al. 1989; Duchek, 1984). Thus, a particular window of expansion (for example, three items) may not produce the same rate of contextual change in both age groups, potentially undermining encoding variability in a group with a slower contextual fluctuation rate (Balota et al. 1989). The present study factorially crossed two age groups (younger, older) with three different expansion schedules: 1-2-3, 1-3-5, and 1-3-8. These were paired with corresponding equal interval schedules with the same average spacing, namely 2-2-2, 3-3-3, and 4-4-4, respectively. These schedules were chosen (a) to determine the benefit of increased average spacing on final test performance; (b) to allow for comparison of results from the current study with previous experiments using these schedules (e.g., Balota et al., 2006); and (c) to determine which schedules produced the best performance in each age group.

It is also known that the benefit of spacing in memory performance is affected by retention interval, such that the benefit of spacing increases when a test is given after a delay compared to an immediate test (the spacing × retention interval interaction; see Crowder, 1976). Expanded retrieval has been proposed to be particularly beneficial for long-term retention of information (e.g., Cull, 2000; Landauer & Bjork, 1978), so one might expect the benefits of expansion to increase with retention interval. Therefore, the current study also included a retention interval manipulation: some subjects took the final test after the learning phase in the same experimental session while others took the final test 24 h after completing the learning phase.

METHOD

Participants

One hundred and four younger adults (M = 19.8 years, SD = 1.1) were recruited from undergraduate courses at Washington University and received course credit for participating. Ninety older adults (66% female; M = 75.7 years, SD = 5.8) were recruited from the Washington University Aging and Development Subject Pool and received $10 for participating. The data of two older adults (both in the same day test condition) were excluded from the analyses: one participant had only 50% retrieval success on the massed presentation trials and one participant had a missing test file due to experimenter error. All participants were given the Shipley Vocabulary test (Shipley, 1940). There were no significant differences in vocabulary scores (number correct out of 40) between older adults (M = 34.0, SD = 3.9) and younger adults (M = 32.5, SD = 3.5), $t(192) = 2.65$, $p > .20$. Older adults did have significantly more years of education (M = 14.6 years, SD = 2.8) than younger adults (M = 13.5 years, SD = 1.1), $t(192) = 3.75$, $p < .001$. Demographic data (available only for older adults) revealed that 93% of older participants identified themselves as White (Not of Hispanic Origin), 3% as American Indian, 3% as Asian, and 1% as Black. No older adults indicated any previous episodes of neurological compromise (such as stroke). When asked to rate their health on a scale of 1 (poor) to 5 (excellent), the average score for older adults was 3.5 (good to very good).

Apparatus

The stimuli were presented via a Dell computer which allowed ms resolution. In order to make the stimuli relatively easy to read for all groups, the stimuli were presented with 40 column resolution.

Materials

The stimuli consisted of 56 pairs of low associates (such as CLOTH SHEEP) that were taken from Thomson and Tulving (1973) and the Nelson norms (Nelson, McEvoy, & Schreiber, 1998). A low associate in the Nelson norms was defined as a cue+target pair that had .01 forward associative strength and .00 backward associative strength. These values were chosen in order to match the added pairs to the Thomson and Tulving pairs, the majority of which were not listed in the Nelson norms. In the learning phase, there were 24 filler items and four critical items within each presentation condition (single, massed, and the three equal interval and expanded schedules). Only critical items were tested in the final test phase. For each expanding schedule there was a corresponding equal interval schedule matched in average spacing. The three pairs were 1-2-3/2-2-2 (Lag 2), 1-3-5/3-3-3 (Lag 3), and 1-3-8/4-4-4 (Lag 4). All conditions were equally distributed throughout the study list on average (e.g., all of the massed items were not clustered at the beginning or end of the list). Average list positions for the conditions were: Single, 70.8; Massed, 70.0; Expanded 1-2-3, 67.3; Expanded 1-3-5, 69.7; Expanded 1-3-8, 69.0; Equal Interval 2-2-2, 70.3; Equal Interval 3-3-3, 72.0; Equal Interval 4-4-4, 68.4. A copy of the exact list structure is available upon request.

Procedure

The experiment consisted of two phases: a learning phase and a final test phase (cued recall). In the learning phase, all pairs were presented intact on the first presentation (e.g., CLOTH SHEEP) for 2.5 s. Pairs were presented only once (single presentation) or were repeated for three retrieval practice attempts, e.g., CLOTH ___. On study trials, subjects were instructed to read aloud and encode the intact pair. The experimenter then coded whether the subject had accurately read the pair (reading errors were made

<1% of the time). On retrieval practice trials, subjects were presented with the left half of a previously studied pair (CLOTH ___). Each cue was presented for a minimum of 2.5 s and stayed on the screen until (a) the subject attempted to verbally complete the pair with a target (e.g., say "cloth *sheep*"); (b) responded "don't know" and did not want to generate an answer; or (c) 15 s had elapsed without a response. Subject responses were coded by the experimenter as correct, incorrect, or no answer.

In the final recall test, items were presented similarly to retrieval practice trials in the learning phase (e.g., CLOTH ___) and subjects were given identical instructions, namely to verbally complete the pair with the target if possible. The item was cleared from the screen as soon as a subject responded or after 15 s had elapsed, with a 1-s ISI between trials. Subject responses were coded by the experimenter as correct, incorrect, or no answer.

Retention interval between the learning and test phases of the experiment was manipulated as a between-subjects variable, with 104 of the subjects (80 younger; 66 older) being in the same day test condition and 48 (24 younger; 24 older) being in the 24-h delayed test condition. In the same day test condition, the test phase of the experiment was administered within the same session as the learning phase (on average 8 min after the learning phase). In the 24-h delayed test condition, subjects completed the learning phase and then returned the next day (between 23 and 25 h later) to take the final test. After completing the final test phase, subjects were given the Shipley Vocabulary Test.

Design

This study was a 4 (Practice Condition) × 3 (Schedule Spacing) × 2 (Age Group) × 2 (Retention Interval) mixed factorial design. Age Group (younger, older) and Retention Interval (same day, 24-h delay) were both between subject variables. Practice Condition (single presentation, massed, equal interval, expanded) and Schedule Spacing (Lag 2, Lag 3, Lag 4) were within-subject variables.

RESULTS AND DISCUSSION

The criterion for significance was set at the .05 level for all analyses.

Learning Phase Retrieval Success Rates

As expected, subjects were 100% accurate on each retrieval attempt in recalling the target words in the massed condition. The mean accuracy performances as a function of Age, Retrieval Attempt and Retrieval Schedule are displayed in Table 1. Older adults had overall lower retrieval success rates than younger adults, $F(1, 188) = 56.25$, $MSE = 3{,}682.44$, $p < .001$. Across all retrieval attempts, all subjects experienced significantly more retrieval success

TABLE 1. Learning phase retrieval success rates by retrieval practice schedule and age group

	Retrieval attempt		
	1	2	3
Younger (N = 104)			
1-2-3	88	89	90
2-2-2	81	84	84
Difference	7	5	6
1-3-5	86	85	85
3-3-3	80	80	81
Difference	6	5	4
1-3-8	87	88	89
4-4-4	78	80	80
Difference	9	8	9
Older (N = 88)			
1-2-3	76	74	71
2-2-2	66	67	66
Difference	10	7	5
1-3-5	73	67	66
3-3-3	63	63	63
Difference	10	4	3
1-3-8	78	75	75
4-4-4	64	64	65
Difference	14	11	10

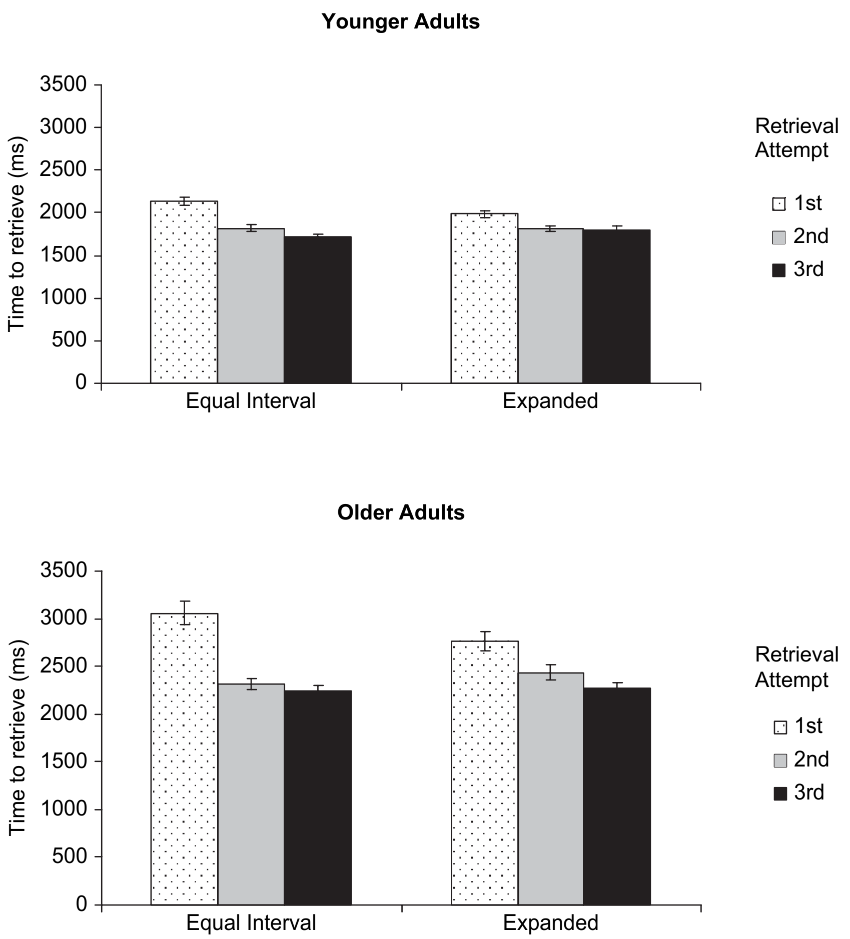
in the expanded retrieval condition than in the equal interval condition, $F(1, 188) = 4.93$, $MSE = 3{,}682.44$, $p < .03$. This is consistent with results from Landauer and Bjork (1978) and Balota et al. (2006) who also found a learning phase advantage for expanded items compared to equal interval items. An Expansion × Retrieval Attempt interaction showed that this advantage for the expanded condition was larger in the first attempt than the subsequent two attempts, $F(1, 188) = 16.69$, $MSE = 44.75$, $p < .001$. There was also an interaction of Retrieval Attempt × Age Group, such that younger adults showed a slight increase in retrieval success over successive retrieval attempts (about 1.8%) and older adults showed a slight decrease across attempts (about –1.9%), $F(1, 188) = 17.51$, $MSE = 41.37$, $p < .001$. This was qualified by a significant Expansion × Retrieval Attempt × Age Group interaction, such that older adults showed a decrease in retrieval success across successive retrieval attempts only in the expanding schedules (about a 4.6% decrease over all expanded attempts) but younger adults did not, $F(1, 188) = 10.56$, $MSE = 44.75$, $p < .01$.

Learning Phase Response Latencies

On study trials, older adults (M = 2468 ms, SE = 44 ms) were overall slower than younger adults (M = 1935 ms, SE = 43 ms), $F(1, 170) = 73.86$, *MSE* = 1,067,365.87, $p < .001$. Reaction times for study trials were similar across all schedules and did not reliably differ from each other, $F(1, 170) < 1$.

Figure 2 shows reaction time data across correct retrieval attempts in the equal interval and expanded retrieval conditions, collapsed across schedule. Only subjects who had at least one observation per condition were used in these analyses. In comparing retrieval times for expanded versus equal interval items, there was an Expansion × Retrieval Attempt interaction indicating that retrieval times became faster at each attempt and this effect was larger in the equal interval conditions, $F(1, 174) = 22.94$, $MSE = 375{,}148.90$, $p < .001$. Thus, using response latencies as an index for retrieval effort, it does not appear that the expanded retrieval condition produces a continuous increase in effort across retrieval attempts, nor does it produce greater retrieval effort

FIGURE 2. Retrieval times for correct responses in the learning phase (in ms).



than equal interval retrieval. An Expansion × Retrieval Attempt × Age Group interaction indicated that older adults showed larger decreases in response latencies across retrieval attempts in the equal interval condition compared to younger adults, $F(1, 174) = 5.55$, $MSE = 375{,}148.90$, $p < .05$.

Final Cued Recall

In the final test phase, there were three primary effects of interest: repetition, spacing, and expansion effects. The massed condition was compared to the single presentation (no practice) condition to provide an index of repetition effects by computing a 2 (Repetition) × 2 (Retention Interval) × 2 (Age Group) mixed-factor ANOVA. The three levels of the equal interval condition (lags 2, 3, and 4) were compared to the massed condition to provide an index of spacing effects by computing a 2 (Spacing) × 3 (Schedule) × 2 (Retention Interval) × 2 (Age Group) mixed-factor ANOVA. Equal interval schedules were compared to the expanded schedules to provide an index of expanded retrieval effects by computing a 2 (Expansion) × 3 (Schedule Spacing) × 2 (Retention Interval) × 2 (Age Group) mixed-factor ANOVA.

The percentage of items recalled in each condition is shown in Figure 3. Not surprisingly, overall, older adults recalled significantly fewer items than younger adults (about 37 vs. 63%, respectively), $F(1, 188) = 84.38$, $MSE = 2{,}419.64$, $p < .001$.

There was also a significant effect of Retention Interval, such that subjects in the delayed test condition had lower overall recall performance than subjects in the same day test condition (about 30 vs. 57%), $F(1, 188) = 85.20$, $MSE = 2{,}419.64$, $p < .001$. There was no Retention Interval × Age Group interaction, $F(1, 188) = 1.49$, $MSE = 2{,}419.64$, $p > .20$.

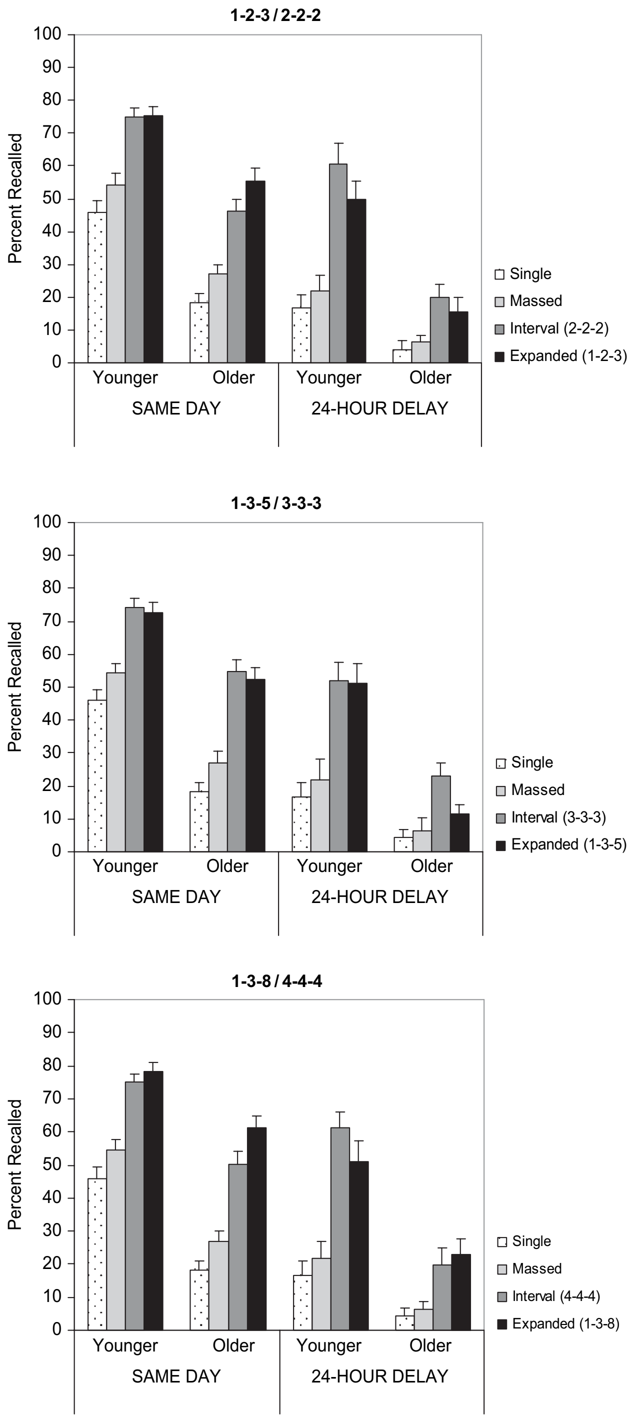
Repetition Effect

There was a significant effect of Repetition, such that subjects recalled more items in the massed condition than the single presentation condition, $F(1, 188) = 6.28$, $MSE = 422.40$, $p < .02$. This Repetition effect did not interact with Age Group, $F(1, 188) < 1$, Retention Interval, $F(1, 188) = 1.01$, $MSE = 422.41$, $p > .30$, nor was there a Retention Interval × Age Group interaction, $F(1, 188) < 1$.

Spacing Effect

There was a main effect of Spacing, $F(1, 188) = 93.15$, $MSE = 416.30$, $p < .001$, such that subjects recalled more items in the equal interval conditions than the massed condition. Contrary to extant literature on the spacing effect, the number of items recalled did not differ between the three spacing conditions (lags 2, 3, and 4), $t(191) < 1$ in all comparisons. There was a significant Spacing × Retention Interval × Age Group interaction, $F(1, 188) = 7.72$, $MSE = 416.30$, $p < .01$. As shown in Figure 4, this interaction indicated

FIGURE 3. Percent correctly recalled on final cued recall test.



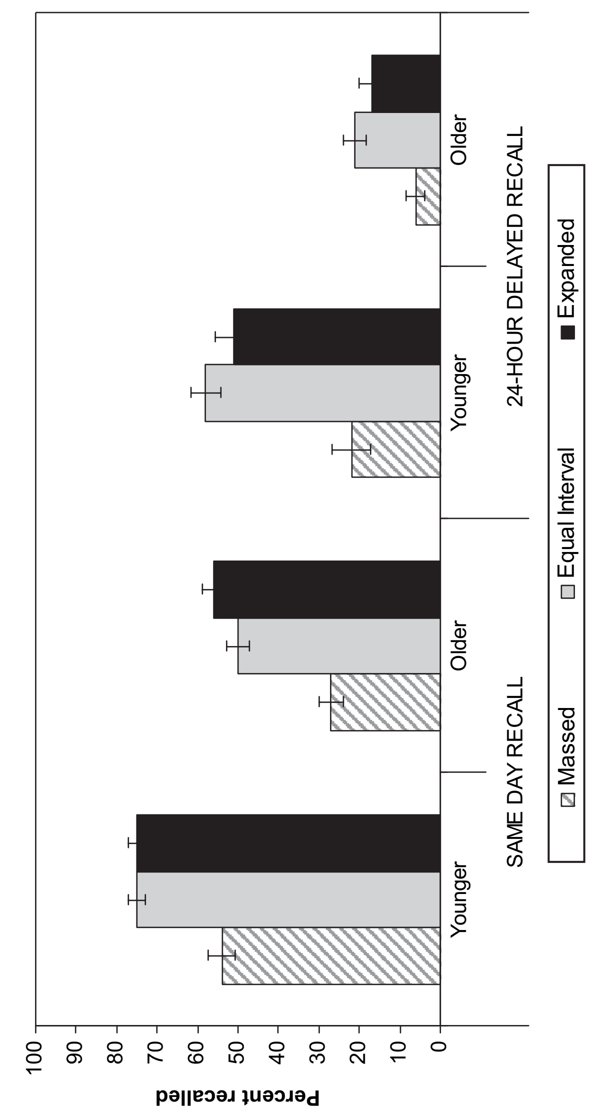


FIGURE 4. Average final recall for items in the massed, equal interval, and expanded condition, collapsed over schedule.

that younger adults showed a larger spacing effect compared to older adults only in the delayed test condition (e.g., a classic spacing × retention interval interaction in the young adult data). On the same day test, the average cued recall benefit collapsed across all equal interval conditions compared to the massed condition was 20.3% in younger adults and 23.4% in older adults, $F(1, 142) = 1.37$, $MSE = 418.601$, $p > .20$. On the delayed test, the average spacing benefit was 36.1% in younger adults and 14.5% in older adults, $F(1, 46) = 6.52$, $MSE = 409.194$, $p < .02$.

Expansion Effect

As shown in Figures 3 and 4, there was a significant Expansion × Retention Interval crossover interaction, $F(1, 180) = 7.98$, $MSE = 386.62$, $p < .01$. In the same day test group, cued recall performance was reliably higher in the expanded retrieval conditions (about 65.9%) compared to the equal interval conditions (about 62.5%), $F(1, 136) = 6.39$, $MSE = 374.91$, $p < .01$. Surprisingly, this pattern was reversed in the 24-hour delayed test group, such that subjects recalled significantly *fewer* items in the expanded conditions compared to the equal interval conditions after a 24-h delay between the learning phase and recall test, $F(1, 46) = 5.65$, $MSE = 418.08$, $p < .05$. On average, subjects recalled about 33.7% of expanded items on a delayed test compared to about 39.4% of equal interval items. There were no significant interactions with Spacing Schedule.

With regard to effects of age, planned comparisons revealed a marginally reliable Expansion × Age Group interaction in the same day test condition, $F(1, 136) = 3.83$, $MSE = 374.91$, $p < .06$. As shown in Figure 4, this interaction indicated that the older adults showed a recall advantage for expanded items compared to equal interval items (about 6%) ($F(1, 63) = 8.79$, $MSE = 391.76$, $p < .01$), but the younger adults did not (about 0.7%), $F(1, 79) < 1$. There were no other significant interactions with Spacing Schedule or Age Group for the delayed test condition.

GENERAL DISCUSSION

The current study was designed to explore why expanded retrieval practice might be a superior form of spaced rehearsal, especially compared to other spaced retrieval schedules that are matched in average spacing. In both younger and older adults, compared to massed practice, we found consistent and robust benefits of spaced retrieval practice in all schedules, whether they were equal interval (2-2-2; 3-3-3; 4-4-4) or expanding schedules (1-2-3; 1-3-5; 1-3-8). However, the specific benefits of using an expanded schedule for retrieval practice (versus a similarly spaced equal interval schedule) were somewhat variable. Both groups showed a memory advantage for expanded items compared to equal interval items during the learning phase. On a same day test, this acquisition advantage translated into an expanded retrieval advantage on the final test in older adults but not younger adults. When tested 24 h after initial acquisition, older adults did not show an expanded retrieval advantage, and younger adults actually showed a significant *disadvantage* for cued recall of expanded items compared to equal interval items.

THEORETICAL IMPLICATIONS OF EXPANDED RETRIEVAL IN YOUNGER AND OLDER ADULTS

Spaced Retrieval Practice

The results from our experiments indicate that both younger and older adults showed substantial benefits of spaced (vs. massed) retrieval practice, no matter which form it took (expanded or equal interval practice). This is consistent with data from Balota and colleagues (e.g., Balota et al., 1989, 2006) that show robust effects of spacing in both explicit and implicit memory measures in healthy older adults and individuals with Dementia of the Alzheimer's Type (DAT).

The lack of a clear lag effect in the current study is an interesting result that is in contrast to previous research in the spacing effect which shows a clear effect of lag within the range of lags we used (one to four items; see Crowder, 1976 for an overview). One obvious difference between the present study and previous research is that we incorporated four coding events of the information and most previous studies on the spacing effect have only included two encoding events. It might be argued that our failure to find a lag effect between schedules implies that we did not test a wide-enough range of schedules to be consistently sensitive to the potential benefits of expanded retrieval practice. It could be that one needs a much larger window of expansion (such as an average spacing of 10 items vs. 4 items) in order to produce benefits of expanded retrieval above and beyond equal interval retrieval practice. The schedules used in the current study were chosen because, in typical spacing studies, lags of one to four usually produce substantial lag effects in memory performance (e.g., see Melton, 1967) and one tends to find a decreasing return on the benefits of spacing beyond a lag of four items. The idea that we may be dealing with too restricted a range of schedules to find expanded retrieval effects is also inconsistent with data from Landauer and Bjork (1978) and Cull et al. (1996). Landauer and Bjork used schedule pairings of 0-3-10/4-4-4 (lag of 4) and 1-4-10/5-5-5 (lag of 5), while Cull et al. used a 1-5-9/5-5-5 (lag of 5) schedule pairing. Our schedule pairing of 1-3-8/4-4-4 was not radically different from their schedule pairings. Indeed, our results are consistent with data from Landauer and Bjork (1978; Experiment 1) who apparently found no effect of lag when comparing performance of various spaced retrieval schedules. Final test performance in their study was not different for items practiced on a 1-1-1, 4-4-4, 5-5-5, and 10-10-10 schedule. It may be that the opportunity for multiple retrieval attempts diminishes the lag effect typically found with one repetition of an item.

Expanded Retrieval Practice

It has been suggested that expanded retrieval might be a particularly effective retrieval schedule because the gradual expansion of intervals between retrieval attempts increases retrieval effort at each attempt while the chance of retrieval success remains relatively high (Carpenter & DeLosh, 2005; Landauer & Bjork, 1978). Using response latency as an index of retrieval effort, there was no evidence for greater retrieval effort in an expanding schedule as the interval between retrieval attempts increased. On the contrary, the greatest retrieval effort appears to occur on the first retrieval attempt. Moreover, the first attempt of the equal interval schedule is apparently more effortful than the expanded schedule, which might be expected given that it comes after a longer delay. Thus, contrary to the original hypothesis, if anything, it appears that expanded retrieval requires less retrieval effort than the equal interval condition.

In fact, our study indicates that any memory advantage produced by expanded retrieval practice is primarily due to a learning phase advantage for expanded items, compared with items practiced on an equal interval schedule. This is consistent with data from Balota et al. (2006) and Landauer and Bjork (1978). Within the schedules used in our experiment, all subjects showed greater learning phase retrieval success for expanded compared to equal interval items. In younger adults, this learning advantage was lost by the final test phase on a same day test, and there was a clear disadvantage in memory for expanded items after 24 h. Older adults were more likely to retain their learning phase advantage for expanded items on a same day test (as noted by the expansion × age group interaction in the same day test condition), although this advantage was also lost in older adults after 24 h. Balota et al. (2006) found similar results; younger and older adults and individuals with DAT showed a learning phase advantage for expanded items but this did not translate into a final recall advantage for expanded items compared to equal interval items. This is consistent with the notion that the expanded retrieval effect in final recall is strongly tied to the acquisition advantage during the learning phase, especially on the first retrieval attempt. Karpicke (2004) found no difference in memory performance when expanded and equal interval items were matched on the timing of the first retrieval attempt (e.g., comparing a 0-2-4 schedule to a 0-2-2 schedule). This was true in the acquisition phase as well as the final free recall test. Carpenter and DeLosh (2005) found similar results on a final test when they equated for timing of the first retrieval attempt in the acquisition phase by comparing a 3-5-7 expanding schedule to a 3-3-3 equal interval schedule.

Thus, although there is a marked acquisition advantage for expanded items during the learning phase, this advantage is not retained over time. This is clearly in contrast to Landauer and Bjork's (1978) assertion that expanded retrieval is particularly beneficial for long-term retention. If expanded items are actually better remembered on an initial test compared to equal interval items, why are they more likely to be forgotten after a delay? Part of the answer may lie in the notion of encoding variability. Contextual information fluctuates over the various spacing intervals (e.g., see Crowder, 1976); presumably, the greater the spacing, the greater the contextual variation. At each retrieval attempt, one can expect that a certain degree of contextual sampling will occur. The extent of this sampling, however, may be determined in large part by the accessibility of the item in memory. As noted by Jacoby (1978), the repetition of an item does not necessarily lead to a repetition of the *processing* involved in encoding the item. One way to conceptualize the benefit of spacing is that it serves to decrease accessibility of an item, which in turn increases re-processing of an item when it is repeated or successfully retrieved (Cuddy & Jacoby, 1982; Jacoby, 1978; Johnston & Uhl, 1976). In a schedule incorporating multiple retrieval attempts, there are multiple chances to re-process an item, but items that are already highly accessible in memory may not encourage much additional contextual sampling. Thus, ease of accessibility in the short term may not necessarily translate into ease of accessibility in the long term if previous retrieval attempts have done little to augment the existing memory trace.

When considering how this applies to expanded retrieval (as tested here), the shorter delay between the original encoding event and the first retrieval attempt may offer an advantage for item accessibility (and thus a greater chance at retrieval success) but a disadvantage for contextual sampling. In other words, it may be that, in an expanded retrieval schedule, the first retrieval attempt after just one intervening item is a relatively *easy* retrieval event but it is also in some sense a wasted one. On the other hand, in the equal interval condition, the longer lag between initial encoding and the first retrieval attempt increases the chance that the item will be forgotten but also should increase the amount of re-sampling that occurs when an item *is* successfully retrieved. This is consistent with findings from Karpicke (2004) and Carpenter and DeLosh (2005) who found no differences in expanded vs. equal interval retrieval when the timing of the first retrieval attempt is equated across conditions.

This concept of a relation between decreased accessibility and contextual sampling may also suggest why older adults in our study showed a benefit for expanded retrieval items on an immediate test while younger adults do not. Although we suggest above that expanded retrieval may have been relatively "easy" for younger adults, retrieval success rates were about 10–15% lower for older adults than younger adults. Expanded retrieval may have been more beneficial in the short term for older adults because they are more likely to experience some decay of information (but not too much) by the first retrieval attempt, possibly enhancing the benefit of early retrieval for expanded items due to increased opportunity for contextual sampling. In other words, the expanded retrieval condition may have yielded a more desirable level difficulty for older adults than younger adults in the short term (e.g., Bjork, 1988, 1994, 1999; Schmidt & Bjork, 1992). However, this benefit was not sustained after a 24-h delay.

The notion of a trade-off between retrieval success and retrieval effort is consistent with recent work by Bjork (1994, 1999; Schmidt & Bjork, 1992) and Pashler (Pashler et al., 2003, 2005) which indicates that longer-term retention benefits from a certain level of difficulty and imperfect performance during initial acquisition of information. Although retrieval success is important during learning and the complete forgetting of information is obviously not desirable, it appears that learning conditions which have high rates of retrieval success and are relatively error-free (such as expanded retrieval) are not particularly effective if the goal is long-term retention, at least with the current schedules. Of course, what constitutes a desirable level of difficulty during learning will differ among individuals and groups, and the work on desirable difficulties has primarily focused on younger adults. An open question is how the principle of desirable difficulties could be effectively incorporated into work with other populations, such as older adults, Alzheimer's patients, or individuals with learning disabilities.

IMPLICATIONS FOR THE USE OF SPACED RETRIEVAL IN MEMORY TRAINING

A primary goal of this study was to investigate the conditions under which spaced retrieval could benefit memory performance in younger and older adults, and in particular, whether expanded retrieval schedules offered a superior form of spaced retrieval practice. The benefits of expanded retrieval differ somewhat depending on age group and whether one is concerned with short- or long-term retention, and this variability may imply different applications of spaced retrieval techniques in memory training.

First, regardless of age group, it is important to note that results from the equal interval and expanded conditions show a dramatic benefit at all lags compared to massed retrieval practice. This adds to the literature that highlights the notion that spaced retrieval in any form makes it an excellent target for a variety of memory interventions (e.g., Balota et al., 1989, 2006; Camp et al., 1996, 2000; Cherry et al., 1999).

Next, what are the implications of these data for interventions and strategies aimed at younger adults? Although there is an acquisition advantage for expanded items during the learning phase, this advantage is quickly lost on an immediate test and actually reverses after a delay of 24 hours. Carpenter and DeLosh (2005; Experiment 2) found a similar disadvantage in an immediate test for expanded items compared to equal interval items in a study of face-name learning. Thus, if the goal is long-term retention, the expanded retrieval procedure and schedules employed here are not the most effective retention strategies for younger adults. Interventions geared toward improving learning and retention in younger adults may do best to create difficult learning and testing conditions by extending the interval between initial study and the first retrieval practice and providing feedback after errors are committed (Bjork, 1994, 1999; Pashler et al., 2003, 2005).

A slightly different recommendation may be in order for older adults, who, at least in the short term, tended to show a benefit from expanded retrieval compared to younger adults. The higher rates of retrieval success during the learning phase for expanded compared to equal interval items consistently translated into an average 6% benefit of expansion over equal interval spacing in older adults' same day final recall. Since this advantage was not observed after a 24-h delay, further research is needed to determine whether this advantage could be extended beyond an immediate test. Two other key questions that remain are whether older adults, like younger adults, would (a) benefit from incorporating larger spacing (or maximizing difficulty by continually decreasing accessibility) during learning, even if this means committing more errors and (b) whether feedback could help them recover from such errors. Balota et al. (2006) administered corrective feedback in their study of spaced and expanded retrieval and found that older adults and individuals with early stage DAT were able to incorporate feedback to improve memory performance at learning and at test. However, they did not compare schedules with varying lags to determine whether pairing corrective feedback with increasing lags would produce even larger benefits of spacing.

Although expanded retrieval did not produce consistent advantages in long-term retention compared to equal interval practice, there may be other reasons to use expanded retrieval as a memory strategy compared to other schedules of distributed practice. First of all, it is important to note that expanded retrieval, as a form of spaced retrieval practice, offers a robust benefit to memory performance compared to *massed* retrieval practice, even after a 24-h delay. In addition, the fact that the expanded retrieval benefit is often linked to higher retrieval success during the initial learning phase may be an advantage in some learning situations. In certain individuals or groups, higher degrees of success during learning may help provide positive feedback, possibly leading to higher rates of compliance and interest in a training program, particularly in those who are often frustrated by difficulties with their memory. To better evaluate the benefit of spaced retrieval, researchers may need to look beyond standardized laboratory memory performance and also examine the preferences of individuals in a training program. For example, a stroke patient with memory difficulties may show greater objective benefits of equal interval practice but express a preference for expanded practice or find it easier than other types of spaced practice. Moreover, it may be possible to precisely titrate retrieval practice schedules according to the specific abilities and deficits of an individual in training (Pavlik & Anderson, 2004). Ultimately, the specific abilities, goals, and preferences of individuals in a given program will help dictate which learning schedules and memory techniques are most suitable for training.

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