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Diminished But Not Forgotten: Effects of Aging on Magnitude of Spacing Effect Benefits

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Objectives. Age-related changes in memory performance are common in paired associate episodic memory tasks, although the deficit can be ameliorated with distributed practice. Benefits of learning episode spacing in older adults have been shown in single-session studies with spaced presentations of items followed by a test. This study examined the magnitude of the spacing effect benefit in older adults relative to younger adults when given a multiday spacing effect paradigm.

Method. We examined the impact of spacing gap (~15 min vs. 24 hr) in younger (N = 51, Mage = 19 years, SD = 0.6) and older (N = 54, Mage = 65 years, SD = 8.8) adults with a 10-day retention interval.

Results. Spacing of learning episodes benefited both younger and older adults. There was an age-related difference in the magnitude of this benefit that has not been observed in earlier studies.

Discussion. These results suggest that spacing benefited the long-term memory of older adults, however the effect was diminished and qualitatively different from that of younger adults.

Key Words: Aging—Memory—Spacing effect.

Background

Studies of cognitive aging show age-related memory differences (e.g., Nyberg, Backman, Erngrund, Olofsson, & Nilsson, 1996; Salthouse, 1991). Episodic memory is particularly susceptible to age-related differences compared with other memory types (e.g., Craik, 1999; Light, 1991; Small, Dixon, & McArdle, 2011). There is considerable evidence that tasks involving learning of word–word pairs, word–nonword pairs (Naveh-Benjamin, 2000), and face–name pairs (Naveh-Benjamin, Guez, Kilb, & Reedy, 2004) are challenging for older adults. Although paired associate episodic memory is affected, spacing of learning episodes (i.e., distributed practice, aka the spacing effect) can improve performance of older adults on these types of tasks (Balota, Duchek, & Paullin, 1989; Balota, Duchek, Sergent-Marshall, & Roediger, 2006; Kornell, Eich, Castel, & Bjork, 2010; Logan & Balota, 2008; Maddox, Balota, Coane, & Duchek, 2011). A review by Cepeda, Pashler, Vul, Wixted, and Roher (2006) failed to locate any multiday spacing effect studies that used an older adult population; in young adults, as the spacing gap between learning episodes increases, so does recall at a future test several days later. This effect has not yet been demonstrated in older adults with spacing gaps and a retention interval of a day or more.

Spacing and Aging

Studies of the spacing effect in older adults typically investigate spacing gaps between the original presentation of a stimulus and the representation(s) of that same stimulus within a single testing session. For example, Balota and colleagues (2006) examined the relative benefits of massed versus spaced retrieval practice. A 5-min distractor task separated the acquisition phase from the cued recall test phase. Spaced retrieval practice produced superior recall at the test episode in both younger and older adults. There was no group × spacing interaction (their study included younger adults, older adults, and adults diagnosed with dementia of the early Alzheimer type), leading the researchers to conclude, "the spacing effect is relatively immune to global cognitive decline or baseline episodic memory performance" (p. 30). Logan and Balota (2008) increased the retention interval from 5 min to 24 hr and again found that spaced retrieval practice improves long-term memory performance of older adults, with no age-related interactions.

In a different paradigm using word pair associations, Balota and colleagues (1989) examined the effect of spacing in a word–word paired associate task in both younger and older adults. In a single experimental session, they presented word pairs once or twice with the second presentation coming either immediately after the first (massed) or following other word pairs (spaced 1, 4, 8, or 20 trials following the first presentation). After a short (2 trials) or long (20 trials) retention interval, participants were asked to provide the missing word of the pair. Thus, this study examined repetition (one or two presentations), different spacing gaps for twice-presented word pairs (0, 1, 4, 8, 20), and two retention intervals (2 or 20). Although older adults did not remember as many words as the younger adults, both

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age groups remembered significantly more words when they saw two presentations of the word pairs rather than just once, and they performed best when the second presentation was spaced compared with when the word presentations were massed. Additionally, for both younger and older adults, recall performance was poorest with longer spacing gaps and a short retention interval, however, when the retention interval was long, recall performance was best for the longer spacing gaps. There was no evidence of any age-related interactions.

Kornell and colleagues (2010) examined the effect of spaced retrieval in a task where participants learned to associate an artist with their paintings. During the learning phase, participants viewed paintings for 5 s during which time the artist's name was announced and presented on the screen. Paintings by the same artist were presented either in sequence (massed) or interleaved with other paintings (spaced). Following a 15-s distractor task, one painting at a time was presented during the test phase and the participant was instructed to select the name of the artist from a list on the screen. Older adults did not remember as many artists as younger adults in this associative memory task, and performance of both younger and older adults was significantly better following spaced presentations of the stimuli compared with massed presentations, again with no age-related interaction. Similarly, in a recent study that also evaluated the effect of spacing on learning of meaningful information, Wahlheim, Dunlosky, and Jacoby (2011) found no age-related difference in the benefit from spacing in learning bird families for younger versus older adults.

Taken together, existing research fails to locate aging-related differences in spacing effect magnitude. However, all existing studies used single-session paradigms, and thus were unable to examine the impact of sleep-related consolidation or other factors introduced when multiday spacing effect paradigms are used.

Spacing Theories

Study-phase retrieval (SPR) (Hintzman, Summers, & Block, 1975; Kornell et al., 2010; Murray, 1983; Thios & D'Agostino, 1976) and contextual variability (Balota et al., 1989; Estes, 1955; Glenberg, 1979) are two theoretical approaches used to explain the spacing effect. According to the SPR class of theories, each time an item is repeated, the participant successfully or unsuccessfully retrieves a previous instance of that item. When SPR is successful, the item's memory trace is enhanced or strengthened, improving performance on subsequent tests.

However, retrieval success alone is not sufficient for explaining memory trace enhancement as testing performance is significantly improved only if the SPR occurs after a delay following the initial encoding. A possible explanation for this spacing benefit is that processing of the item during the second presentation is more elaborate in spaced retrieval than in massed retrieval. According to this type of account, in massed retrieval the second presentation retrieval is based on processing superficial sensory features of the second stimulus due to the recent successful first presentation retrieval. Spaced retrieval presumably involves reconstruction-based retrieval of the first presentation based on deeper processing of the second item such as analysis of semantic meaning.

Although SPR is a compelling spacing effect theory, it is not the only viable account of this phenomenon. Contextual variability theory (Estes, 1955; Glenberg, 1979; Balota et al., 1989) suggests that internal and external retrieval cues associated with items as they are learned fluctuate over time, even within a single testing session. Greater temporal separation between learning episodes increases the likelihood that contextual cues associated with a given item will differ, leading to improved retention when learning episodes are spaced, compared with when they are massed.

In order for spacing to be beneficial, especially over long delays, the gap between presentations must be large (e.g., Balota et al.,1989) but not so large so that retrieval is unlikely (Cepeda et al., 2006; Cepeda, Vul, Rohrer, Wixted, & Pashler, 2008; Glenberg & Lehmann, 1980; Mozer, Pashler, Cepeda, Lindsey, & Vul, 2009; Verkoeijen, Rikers, & Ozsoy, 2008). In other words, for a given retention interval there is an optimal study gap with performance decreasing on either side of that ideal gap: a "moderate" amount of spacing between study sessions appears to be desirable. Determining how much spacing is "moderate" (and thus ideal) is not a simple problem because study gap and retention interval interact nonlinearly (Cepeda et al., 2006, 2008). Cepeda and colleagues (2009) systematically varied study gap and retention interval and found that for younger adults, when the retention interval is long (specifically, 10 days), a spacing gap of 24 hr is ideal.

Current Study

Current theories of the spacing benefit rely on contextual binding and encoding variability, which ensure that memory retrieval is successful and yet appropriately difficult (but not too difficult). However, older adults have demonstrated reduced binding of items to contexts (Howard, Kahana, & Wingfield, 2006; Puglisi, Park, Smith, & Dudley, 1988) and reduced elaborative encoding (Craik & Byrd, 1982), which may result in a decrement to the size of the spacing effect. Contrary to this prediction, spacing effect studies that compare younger and older adults (e.g., Balota et al., 1989; Kornell et al., 2010) have not found age-related differences attributable to spacing gap. However, these existing studies examined spacing within a single session and over a short period of time. The current study involves the retention of information over a long delay (10 days) and includes an immediate study session (~15 min after the first learning session) or study session delayed by 24 hr (spaced). Unlike other spacing studies, word pairs were not repeated one after the other in our study (in such a manner that learning was strictly massed). Rather, participants were asked to relearn an entire list of word pairs either immediately after the first learning session or after a 24 hr delay (and then were tested 10 days following Session 2 recall). Given the findings of others that older adults' retrieval is less context-based than that of younger adults (Howard et al., 2006), and older adults use less elaborative encoding (Craik & Byrd, 1982), with a long spacing gap (24 hr) and long retention interval (10 days) we anticipate that older adults should have greatly reduced access to separate retrieval cues compared with younger adults. In essence, our prediction is that long delays may reduce or even eliminate the spacing effect for older adults. Whereas other studies have found that older adults benefit from spacing to the same degree as do younger adults, due to age-related differences in encoding and contextual binding, older adults may not show the same spacing benefit at longer, more meaningful spacing gaps and retention intervals.

The present study replicated an earlier finding of a long-lasting spacing advantage in young adults in a paired associate word task (English translations of Swahili; Cepeda et al., 2009) and then examined whether this advantage extends to older adults. Previous research found equal spacing effect benefits for younger and older adults within a single testing session (e.g., Balota et al., 1989; Kornell et al., 2010). Earlier studies, however, only examined single-session learning. In the present study, once criterion was reached in an initial encoding session, participants either studied all the word pairs again (massed but discrete learning episodes) or they studied them 24 hr later (spaced), with a 10-day retention interval. It is possible that retrieval in the spaced condition will be too difficult, perhaps due to encoding and contextual-binding challenges associated with older adults, which would eliminate a spacing effect at longer test delays. If retrieval in the spaced condition were impaired due to age-related differences in encoding and contextual binding, we predicted that, unlike younger adults, older adults would show a reduced or no benefit from spacing in this study.

Method

Participants

Younger ($N = 51$, Mage = 19 years, $SD = 0.6$) and older ($N = 54$, Mage = 65 years, $SD = 8.8$) adults participated in this study. Younger adults were recruited from the participant pool at Santa Clara University and received research credit for their participation. Older adults were recruited from the Santa Clara Senior Center and were compensated $20.00 for their participation. Participants were predominantly women (81% younger adults, 88% older adults). The older adults were college-educated and reported they were in good health. Participants in both age groups were randomly assigned to either massed (immediate testing of Session 2, with an average gap of ~15 min between learning and relearning of an average word pair) or spaced (24 hr delay before Session 2 testing) conditions. There were 28 younger and 28 older adults in the massed condition and 23 younger and 26 older adults in the spaced condition.

Materials and Procedure

Participants learned 20 Swahili–English word pairs of varying parts of speech using the same software used by Cepeda and colleagues (2009), Experiment 1. Testing occurred individually for all participants. For any given participant, all sessions were completed individually in the same room and on the same computer that controlled stimulus presentation and recorded participant responses and response times.

The first study session consisted of two parts: acquisition and recall (repeated testing with feedback). In the acquisition phase, the 20 Swahili–English word pairs were presented in random order. Word pairs appeared in black, all caps text on a grey background for 7 s. Immediately following the presentation of the 20 word pairs, the program presented one Swahili word at a time, directly above a text field in which participants could type a response. Word order was randomized such that all 20 Swahili words were presented once without replacement. After entering a response, participants pressed the "Enter" key to proceed to the next word in the list of 20. Participants were given corrective feedback following each response. The program cycled through all 20 Swahili words until participants correctly translated a Swahili word 2 times. At this criterion the participants were considered to have learned the word pair and it was removed from subsequent list iterations. In other words, only Swahili words that participants did not respond to correctly 2 times continued to be presented. Spacing of word presentations was not controlled during the encoding session. Once all 20 Swahili words were correctly translated twice, the first session ended.

Participants completed the second study session either immediately following the first session (massed condition; ~15 min between sessions) or 24 hr later (spaced condition). The second session was identical to the first except that it consisted of only two presentations of the 20 word list in randomized order (i.e., all 20 word pairs were presented once, in random order, before the words were presented a second time, again in randomized order).

The third (test) session occurred 10 days following the second study session and consisted of a final recall test where each Swahili word was displayed directly above a text field in which participants could type a response. No feedback was provided and the session was complete after the entire randomized list was presented once.

Results

Session 1 (Encoding)

The data analyzed from the first session were the number of trials required to reach the criterion of entering the correct

English word for each Swahili word in two presentations of each Swahili word. Data were analyzed using a 2 × 2 factorial analysis of variance (ANOVA) with age (young vs. old) and spacing (massed vs. spaced) as between-subjects factors. Session 1 data from one young adult were missing and thus are not included in this analysis. There was a significant main effect of age, $F(1, 100) = 475.3$, $p = .001$, $\eta_p^2 = .312$, and no main effect of spacing, $F(1, 100) = 3.5$, $p = .06$ or interaction, $F < 1$. Thus, older adults required more trials in order to reach the criterion of 100% accuracy twice on all 20 Swahili words compared with younger adults ($M = 135.9$ trials [$SD = 62.5$] and $M = 73.9$ trials [$SD = 20.7$], respectively). On average, participants in the massed condition cycled through 15 more trials than those in the spaced condition to reach criterion in Session 1. This difference did not reach significance.

Session 2 (Relearning via Testing With Feedback)

The key data from the second session were the number of correct responses to the Swahili word prompts. As the list was presented to participants twice, the maximum possible score was 40. The data were evaluated using a 2 × 2 factorial ANOVA with age (young vs. old) and spacing (massed vs. spaced) as between-subjects factors. There was a significant main effect of age, $F(1, 101) = 78.2$, $p = .001$, $\eta_p^2 = .437$ and spacing, $F(1, 101) = 5.1$, $p = .026$, $\eta_p^2 = .048$, but no interaction, $F(1, 101) = 3.5$, $p = .064$ was found. Younger adults remembered $M = 36.9$ ($SD = 3.0$) and $M = 36.4$ ($SD = 3.6$) words in the massed and spaced conditions, respectively, whereas older adults recalled $M = 28.6$ ($SD = 8.4$) and $M = 23.8$ ($SD = 6.9$) words, respectively. Older adults made more errors than younger adults, and both groups made more errors in the spaced condition, however, younger adults' performance was near ceiling in both conditions, making the marginally significant interaction difficult to interpret. Although Session 1 criterion was the same for younger and older adults (correctly recalling each word pair twice), younger adults showed virtually no forgetting over a 24 hr delay, whereas older adults recalled fewer words in both the massed and spaced conditions.

Session 3 (Final Test)

The number of correct responses in the test session (out of 20 possible; see Figure 1) was analyzed using a 2 × 2 factorial ANOVA with age (young vs. old) and spacing (massed vs. spaced) as between-subjects factors. Both the main effect of age, $F(1, 101) = 43.5$, $p < .001$, $\eta_p^2 = .30$ and spacing, $F(1, 101) = 34.9$, $p < .001$, $\eta_p^2 = .257$, were significant as was the age × spacing interaction, $F(1, 101) = 6.5$, $p = .012$, $\eta_p^2 = .061$. Two a priori tests compared massed and spaced performance for each age group separately and showed a significant benefit of spacing for both younger ($t(49) = 6.2$, $p < .001$) and older adults ($t(52) = 2.3$, $p = .025$). Thus, spacing improved recall for both younger and older adults, although to a lesser degree for older adults.

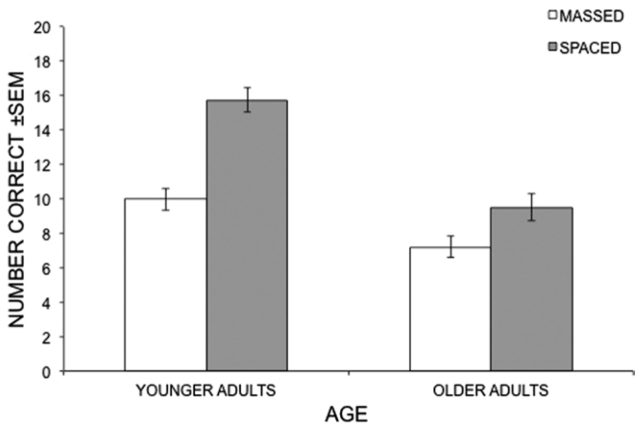

Figure 1. Session 3 performance for massed and spaced conditions as a function of age, showing the number of items recalled correctly out of 20 possible.

Predicting Test Performance: Easy- vs. Hard-to-Learn Words

A possible predictor of third session test performance is the pattern of first session success in responding to the word pairs. Some words were easier to learn than others for each participant. For example, one participant may have learned the rangi–paint word pair association in only 4 trials but the jani–grass word pair might have required 20 trials, whereas another participant might have found the jani–grass word pair easy to learn. We explored whether the number of trials required to learn each word pair, as each participant learned it, could be a factor in determining which words they recalled at test. Specifically, word pairs that were easy to learn in Session 1 may or may not have been easy to recall in Session 3. Easy-to-learn words were identified by how quickly the participant reached criterion (correct twice) in Session 1. The 20 word pairs were sorted into quartiles based on how quickly each participant learned the word pair. For example, one quartile contained the five words that were quickly learned and another contained the five words that took the most trials to learn for each participant.

These data, shown in Figure 2, were analyzed using a 2 × 2 × 4 mixed ANOVA with age (old vs. young) and spacing (massed vs. spaced) as between-subject factors and quartile (Q1–Q4) as within-subject factor. All main effects were significant: age, $F(1, 101) = 31.8$, $p < .001$, $\eta_p^2 = .24$, spacing, $F(1, 101) = 28.4$, $p < .001$, $\eta_p^2 = .220$, and quartile, $F(3, 303) = 48.7$, $p < .001$, $\eta_p^2 = .325$. Effects are as predicted, with lower performance for harder to learn words, older adults, and massed items. Additionally, there was a significant age × quartile interaction, $F(3, 303) = 15.3$, $p < .001$, $\eta_p^2 = 0.132$, reflecting that young adults had little difficulty remembering hard-to-learn items after a 10-day retention interval, whereas

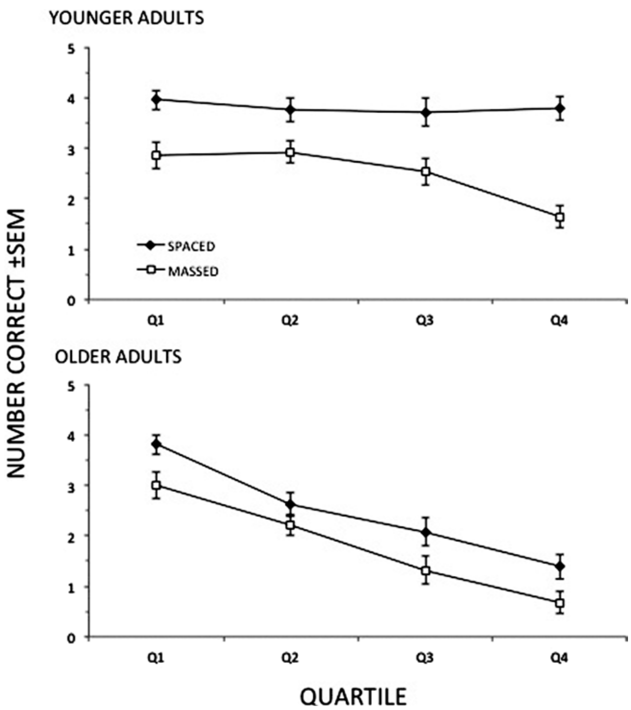

Figure 2. Session 3 number correct, organized in quartiles (by age) as a function of when participants correctly responded to the words presented in Session 1 (i.e., first five words, second five words, etc.).

older adults did have difficulty with the harder items. No other interactions were significant (age × spacing, $F(1, 101) = 2.7$, $p = .106$; spacing × quartile, $F(3, 303) = 2.5$, $p = .059$; and age × spacing × quartile, $F(3, 303) = 1.6$, $p = .191$). The marginally significant spacing × quartile interaction indicates that spacing effect magnitude might be larger for hard-to-learn items; specifically, massing appears detrimental to hard-to-learn items. Surprising, the age × spacing interaction failed to reach significance with quartile included as a factor, suggesting that further research is needed to determine if the age × spacing interaction depends on item difficulty (perhaps using an explicit difficulty manipulation).

Given the main effect of spacing and a significant interaction with quartile, we conducted two additional analyses investigating each age group separately with a 2 × 4 mixed ANOVA with spacing and quartile as factors. For the younger adults, both main effects were significant: spacing, $F(1, 49) = 25.1$, $p < .001$, $\eta_p^2 = .339$, and quartile, $F(3, 147) = 4.3$, $p = .006$, $\eta_p^2 = .081$ as was the interaction, $F(3, 147) = 3.0$, $p = .034$, $\eta_p^2 = .057$. For the older adults both main effects were significant: spacing, $F(1, 52) = 6.7$, $p = .013$, $\eta_p^2 = .114$, and quartile, $F(3, 156) = 73.7$, $p < .001$, $\eta_p^2 = .586$. The interaction, however, was not significant, $F < 1$. The results of our analyses suggest that (a) there is a differential effect of spacing for younger adults as a function of quartile (i.e., spacing facilitates recall, particularly for later-learned words) and (b) spacing facilitates recall for older adults, but not differentially as a function of when they learned the words in the first session. Although words that were learned first were most likely to be recalled in the test session, spacing improved test session performance for both easy- and hard-to-learn words for both younger and older adults, but spacing particularly helped younger adults remember the hard-to-learn words.

Discussion

We examined the spacing effect using a paired associate learning task with both younger and older adult participants. Our results demonstrate clearly that spaced practice improves recall for younger adults and, to a lesser degree, for older adults. Participants showed improved recall in our memory task 10 days following their last study session when study sessions were spaced 24 hr apart compared with when they were retrieved soon after learning. This finding extends previous research on the benefits of spacing for older adults by increasing the lag to 24 hr and increasing the retention interval to 10 days.

Previously, the benefits of spacing effects for older adults have only been demonstrated with substantially shorter lags and retention intervals (e.g., Kornell et al., 2010). At these short lags there was no evidence of an age-related difference in the spacing effect. However, with the 24 hr gap and 10-day retention interval, we found an age-related spacing difference. Our data suggest that the reduced benefit of spacing seen in older adults may be due to their inability to recall the hard-to-learn words in this study. The quartile analysis showed that the pattern of responding was different for younger and older adults. While both age groups showed a significant benefit to spacing over the 10-day retention interval, both older and younger adults were successful in remembering the easy-to-learn words. However, younger adults showed a spacing by quartile interaction, in that they remembered many more of the hard-to-learn words compared with the massed participants. Older adults did not show this interaction. Rather, spacing slightly boosted their performance of all words compared with massed participants. They did not receive an added benefit to the hard-to-learn words that the younger adults did. In summary, spacing did improve long-term memory performance in older adults, but the benefit was both quantitatively and qualitatively different from that of younger adults.

Older adults required nearly twice as many trials to reach criterion in the encoding session. And, minutes after first learning the material during, older adults had forgotten nearly 30% of what they learned (28.6/40), contrasted with only 8% loss in young adults (36.9/40). This loss clearly translated into a lower base rate of performance in the final test session. Younger adults correctly recalled most words in massed (92.2%) and spaced (91%) conditions in the second session. Older adults only correctly recalled 71.5% (massed) and 59.5% (spaced) of the words in Session 2. The retrieval rates for older adults were far below ceiling, suggesting difficulty with the task not experienced by younger adults, which may be a consequence of elaborative encoding or contextual binding differences between younger and older adults (Craik & Byrd, 1982; Puglisi et al., 1988). Although items were recalled correctly during the first study session, older participants did not have great success in recalling those words during the second study session, even when that retrieval immediately followed the first session (i.e., even in the massed condition). It is possible that the learning criterion of this study (recall word pairs correctly 2 times) did not equalize learning in both age groups. Recently, Wahlheim and colleagues (2011) showed that self-pacing during the encoding session equalized performance of younger and older adults, who then showed an equivalent benefit of spacing over a short delay. However, this finding of a rapid forgetting rate of older adults compared with younger adults is not uncommon (e.g., Maddox, Balota, Coane, & Duchek, 2011), and although recall in Session 2 did influence how much is remembered in the study and test session, even with a lower rate of overall performance, older adults showed a benefit to spacing over massing, meaning that even with the initial encoding and retrieval differences, distributed practice did improve long-term memory of older adults.

Recently, Maddox et al., (2011) found age-related differences in the spacing effect were due to age-related impairment in working memory. In a series of experiments exploring the benefits of systematic versus nonsystematic spacing expansion, they concluded that regardless of spacing schedule, older adults performed best when they first retrieved the information soon after initial encoding, whereas younger adults maintained the information in working memory over longer spaced presentations. In our study, performance of older adults was best when the words were retrieved 24 hr later rather than immediately following initial encoding, and these results are not likely explained by working memory limitations in older adults (Hayes, Kelly, & Smith, 2012).

In summary, memory performance in paired associate learning tasks improves in older adults when a second retrieval episode is 24 hr following the initial learning session compared with immediately after the initial learning session, an improvement that is evidenced 10 days later, as it does in younger adults, but differentially and not to the same degree. Two current theories of spacing emphasize the role of elaborative encoding and binding of contextual elements, both of which have been shown to be challenging to older adults (Craik & Byrd, 1982; Puglisi et al., 1988). Therefore, the age-related effect we found in this study may be due to age-related changes in contextual binding and/or elaborative encoding, which affected recall—particularly of hard-to-learn words. One practical implication of the present results is that older adults should space study sessions as a means to reduce aging-related memory difficulties, because even though they do not receive the same benefit to long-term retention as younger adults, performance does improve. Whether older adults have an equivalent gap by retention interval curve as younger adults (Cepeda et al., 2008, 2009), and show the same optimal gap, deserves future investigation.

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