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Age-Related Differences in the Impact of Spacing, Lag, and Retention Interval

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An experiment is reported that examines age-related differences in the lag effect and its relation to retention interval. A total of 30 young and 30 older adults received both once-presented pairs and twice-presented pairs that were tested in a continuous cued-recall paradigm either after a short retention interval (2 pairs intervening between the last presentation of a pair and its test) or a long retention interval (20 pairs intervening between the last presentation of a pair and its test). In addition, the twice-presented pairs were separated by either 0, 1, 4, 8, or 20 intervening pairs. The results replicated the interaction between retention interval and lag that has been reported by Glenberg (1976, *Journal of Verbal Learning and Verbal Behavior, 15,* 1–16). Furthermore, although the older adults performed considerably lower than the younger adults in overall recall performance, their data were remarkably similar to the younger adults in the patterning of means. A mathematical modeling procedure was used to fit the data to Estes' stimulus fluctuation model. The results of this modeling procedure suggest that, compared with younger adults, older adults (a) encode less contextual information at a given point in time and (b) have a slower rate of contextual fluctuation across time.

A common complaint of older adults is a decline in memory performance, and indeed the experimental evidence indicates that older adults show poorer memory performance than younger adults across a wide variety of tasks (Burke & Light, 1981). Given this age-related memory decrement, it is important to understand the theoretical mechanisms that produce the decrement. One possibility that has received attention in the literature is the notion that older adults are deficient at using context in both encoding and retrieval.

The context-deficient processing notion has been at the center of several recent studies. For example, in cued recall it has been found that the memory performance of younger adults benefits more from a context-specific or a uniquely generated retrieval cue than a general category cue; whereas the memory performance of older adults benefits more from a general category cue than a context-specific retrieval cue (Craik & Simon, 1980; Perlmutter, 1979; Rabinowitz & Ackerman, 1982). Also, it has been demonstrated in an encoding specificity paradigm that older adults show less of a cue compatibility effect than younger adults, especially with weak associates (Duchek, 1984; Rabinowitz, Craik, & Ackerman, 1982). That is, older adults' recall is not enhanced as much as that of younger adults when there is a match between the encoding and retrieval context.

These studies have been interpreted as suggesting that older adults do not use context as much as younger adults do to aid memory performance. One of the goals of the present study is to further explore this hypothesis. In pursuit of this goal, we addressed age-related changes in the lag effect. The lag effect refers to the finding that as one increases the number of items presented between the first and second presentation of a repeated item, delayed recall performance increases. This basic finding in verbal learning and memory is consistent with the classic notion that spaced practice leads to better retention than massed practice. Interestingly, however, when one considers immediate recall performance (i.e., recall performance with a short retention interval), one finds that performance actually decreases with increasing lags. Thus, one finds a theoretically important crossover interaction in which at long retention intervals, recall performance increases with increasing lags, whereas at short retention intervals, recall performance decreases with increasing lags (see Glenberg, 1976; Peterson, Wampler, Kirkpatrick, & Saltzman, 1963; Sperber, 1974).

Crowder (1976) and Glenberg (1976) have suggested that this crossover interaction can be best accounted for by a variant of encoding variability theory that places emphasis on the notion that contextual information naturally fluctuates across time. According to this framework, when the same item is repeated within a list, that item can be encoded in a slightly different way at each presentation because of changes in the context of the encoding situation. Changes in the encoding context can be due to a number of factors, such as a change in the experimental situation, a change in the internal state of the subject, a change in the subject's strategy, attention, motivation, and so on. As more time elapses between the two presentations of the same item, there is a greater likelihood of changes in the encoding context. Consider, for example, a continuous paired-associate task. On first presentation, both the stimulus and response (e.g., *star–deer*) will be encoded along with the available contextual

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information. On second presentation, the pair, *star–deer,* will again be encoded along with the available contextual information. Because the contextual information available will change as a function of time, when the lag between the two presentations is short, there will be little difference between the contextual information available during the item's first and second presentations. Thus, there will be a greater chance at short lags that the same contextual information will be available for encoding on both presentations, thereby making that contextual information especially useful, when available, at retrieval. On the other hand, when there is a long lag between the two presentations, there is a greater chance that the context will change between the two presentations, and therefore the contextual information that is encoded on both occasions is more likely to be different. Thus, at the long lag, there will be more unique contexts encoded, none of which will be encoded as well as the contextual information that was available at both presentations at the short lag.

Within this framework, recall performance is predicted by the overlap between the encoded context and the retrieval context. Thus, in addition to the interpresentation lag, the retention interval or time between the second presentation and the test is crucial in determining recall performance. At a short retention interval, the retrieval context is more likely to overlap with the encoding context of the second presentation. Moreover, as noted earlier, at short lags the second encoding context should also closely match the first encoding context. Therefore, at a short retention interval, recall performance should be relatively high in the short lag condition because subjects have had two opportunities to encode a context that should be useful at retrieval. On the other hand, at the long retention interval the retrieval context should not match either the first or second encoding contexts. Therefore, at the long retention interval, recall performance should be higher in the long lag condition because, as noted earlier, this condition results in more unique contexts being encoded. The suggestion here is that if sufficient time has passed for context to change before recall (i.e., at a long retention interval), the subject will benefit from having more unique encoded contexts available, such that one might match the new retrieval context. Thus, this encoding variability framework correctly predicts better recall with (a) short lags and short retention intervals and (b) long lags and long retention intervals.

The present study relies on this theoretical characterization of the Lag × Retention Interval interaction to further explore the age-related context-deficient-processing hypothesis. At first glance, it would appear that if older adults are less sensitive to contextual information at both encoding and retrieval, compared with younger adults, then one might expect a decreased impact of lag at both short and long retention intervals. That is, within the preceding framework, one factor that contributes to the crossover interaction between lag and retention interval reported for younger adults is the change in contextual information. However, as noted, this factor alone does not account for the crossover interaction. That is, one must also consider the rate of contextual change across time. Thus, in order to provide a complete account of the crossover interaction, it is necessary to consider *both* the encoding of contextual information and the rate of change in the available contextual information across time. Older adults could produce decrements in either, both, or neither of the processes. Thus, in addition to providing information regarding an Age × Retention Interval × Lag interaction, the present study uses the mathematic tractability of Estes' (1955, 1959) classic stimulus-sampling model to obtain parameter estimates for both the probability of encoding contextual information and the rate of contextual fluctuation across time. As Crowder (1976) noted, this basic model has provided an elegant account for a wide range of both animal and human behavior. To our knowledge, the present study is the first application of this model to the issue of age-related memory loss.

The present study closely followed Glenberg's (1976) method. That is, a continuous paired-associate task was used, wherein both the lag between repeated paired associates (0, 1, 4, 8, or 20 intervening pairs) and the retention interval (2 or 20 intervening pairs between an item's second presentation and test) were orthogonally varied. Also, once-presented items were included to address the impact of simple repetition.

Method

Subjects

In all, 30 healthy young men and women from Iowa State University (ages 18–25 years; *M* age = 20 years; *M* education level = 14 years) and 30 healthy older men and women (ages 61–76 years; *M* age = 69 years; *M* education level = 15 years) participated in the experiment. The young adults participated to fulfill a course requirement, and the older adults were volunteers from local senior citizen groups in the Ames, Iowa, area. The older adults reported being both physically and mentally healthy for their age, engaged in community activities, and able to independently obtain transportation to the testing location.

Apparatus

All stimuli were presented by an Apple IIe microcomputer.

Materials

A list of 186 paired associates was constructed, consisting of 120 twice-presented pairs, 60 once-presented pairs, and 6 buffer pairs. The pairs were common nouns that had no obvious preexperimental association (e.g., *kitten–dime*). There were 10 twice-presented experimental conditions; Five Lags (0, 1, 4, 8, or 20 intervening pairs) × Two Retention intervals (2 or 20 intervening trials between the item's second presentation and its test), and two once-presented experimental conditions (2 or 20 intervening trials between the item's presentation and its test). For the twice-presented items, there were 12 pairs/condition yielding the 120 twice-presented pairs. For the once-presented items, there were 30 items for each retention interval, yielding the 60 once-presented pairs. There were also 6 buffer pairs used.

Each item served in each of the 12 experimental conditions. For the first 10 subjects, the pairs assigned to the twice-presented conditions rotated across the 10 twice-presented conditions, and the pairs assigned to the once-presented conditions alternated across successive subjects at the two retention intervals. For Subjects 11–20, the 60 items that were used for Subjects 1–10 in the once-presented conditions were switched with 60 of the 120 items that were used in the twice-presented conditions. Finally, for Subjects 21–30, the 60 items that were used for the once-presented items for Subjects 11–20 were switched with the remaining twice-presented items that had yet to appear in the once-presented conditions. Thus, item pairs were completely counterbalanced across conditions.

The entire list consisted of 486 events (presentations and tests): 240

twice-presented pairs, 120 twice-presented pair tests, 60 once-presented pairs, 60 once-presented pair tests, and 6 buffer pairs. In order to achieve the correct sequencing of lags and retention intervals within the list, 6 buffer pairs were interspersed throughout the list but were never tested. Occasionally, for the twice-presented pairs, the lag or retention interval varied between plus or minus one event from the specified lag or retention interval (e.g., a lag of 7 instead of the specified lag of 8). For the once-presented pairs, the retention interval varied between minus one and plus two events from the specified retention interval. These ranges are well within the limits reported by Glenberg (1976).

Procedure

All of the subjects were tested individually. Subjects were seated comfortably in front of the cathode ray tube (CRT). The experimenter was seated nearby such that she also could see the CRT and use the keyboard to type in the subject's oral response.

The duration for each trial was approximately 4 s. During each study trial, the stimulus–response pair was presented simultaneously (e.g., *kitten–dime*). A test trial included the presentation of the stimulus item followed by two question marks (e.g., *kitten ??*). On test trials, subjects were instructed to respond with the appropriate response item or guess if they were unsure. The experimenter then typed in the subject's response. On trials in which no response was given in the alloted time period, the experimenter simply typed *aaaa*. The next trial was initiated by the experimenter pressing the *return* key on the Apple keyboard. Subjects were instructed and prompted by the experimenter to give a response within 4 s in order to keep the timing among the events constant. If the subject gave the response in less than 4 s, the experimenter would wait the appropriate time before proceeding to the next trial. The experimenter used a stopwatch to keep timing across trials relatively constant at 4 s.

Results

The mean percentage correct recall was calculated for each cell per subject. These means were then submitted to an analysis of variance (ANOVA) with age, retention interval, and lag as factors. A separate analysis with the factors age and retention interval was conducted on the once-presented items. Although subjects was treated as the only random factor in this analysis, it is important to note that because items served in different conditions for different subjects, the error term includes variability across items. Therefore, any reported significant effects should generalize across both subjects and items.

Figure 1 displays the mean percentage correct recall as a function of age, lag, and retention interval. There are three points to note in Figure 1. First, as expected, older adults showed lower recall performance than the younger adults. Second, for both groups, one can see that at the short retention interval (RI-2) recall performance decreased between the lags of 1 and 20, whereas at the long retention interval (RI-20) recall increased between the lags of 1 and 20. The reason we are emphasizing the difference between lags 1 and 20 as opposed to lags 0 and 20 is that at lag 0 there is massed presentation of the pairs, and performance may be qualitatively different from the spaced conditions because of other factors (e.g., attentional factors) that do not play as strong a role in the spaced conditions. We shall return to the comparison of massed versus spaced items later.

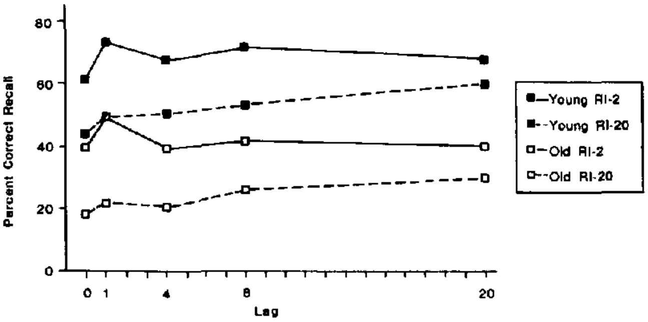

Figure 1. Mean percentage correct recall for the twice-presented pairs as a function of age, retention interval, and lag.

The results from the aforementioned ANOVA supported these observations. There were significant main effects of age, $F(1, 58) = 21.48$, $MS_e = 5168.2$, $p < .001$; lag, $F(4, 232) = 7.32$, $MS_e = 218.2$, $p < .001$; and retention interval, $F(1, 58) = 145.69$, $MS_e = 327.6$, $p < .001$. In addition, this analysis yielded a highly significant Lag × Retention Interval interaction, $F(4, 232) = 8.34$, $MS_e = 132.5$, $p < .001$. None of the remaining interactions between age and the other variables approached significance (all Fs < 1.00). Clearly, the interaction between lag and retention interval replicates a relatively complex pattern of data reported by Glenberg (1976). More importantly, both the younger and older adults produced this same precise pattern.

In order to further specify the nature of the Lag × Retention Interval interaction, planned orthogonal comparisons based on the MS_e from the overall significant interaction were conducted. As described at the beginning of the article, increasing lags should facilitate recall performance at the long retention interval but should lower performance at the short retention interval. In order to test this prediction we compared the mean of lag 1 with the mean of lag 20 for the short retention interval and separately for the long retention interval. The results of these comparisons indicated that performance significantly *decreased* between lag 1 and lag 20 for the short retention interval, $t(59) = 2.38$, and significantly *increased* between lag 1 and lag 20 for the long retention interval, $t(59) = 3.34$. In addition, separate comparisons for the young adults and the older adults overall yielded a similar pattern of effects. For the younger adults, the difference between lag 1 and lag 20 did not reach significance for the short retention interval, $t(29) = 1.24$, but was significant for the long retention interval, $t(29) = 2.70$. For the older adults, the difference between lag 1 and lag 20 was significant both at the short retention interval, $t(29) = 2.13$, and at the long retention interval, $t(29) = 2.02$, $p < .05$, directional. Thus, these results overall replicate the important crossover interaction reported by Glenberg (1976).

The results of the analysis on the once-presented items yielded significant main effects of age, $F(1, 58) = 24.95$, $MS_e = 837.1$, $p < .001$, and retention interval, $F(1, 58) = 97.09$, $MS_e = 54.8$, $p < .001$. However, the interaction between age and retention interval did not reach significance ($p = .09$). The means for the younger adults were 51% and 36% correct for the short and long retention intervals, respectively, and the means for the older adults were 23% and 12% correct for the short and long retention intervals, respectively.

In order to address whether there was any differential sensitivity to repetition, we collapsed across the lag and retention interval for the twice-presented conditions and across retention interval for the once-presented conditions. The means for the younger adults were 43% and 60% for the once-presented and twice-presented pairs, respectively, and the means for the older adults were 17% and 37% for the once-presented and twice-presented pairs, respectively. Thus, the younger adults showed a 17% repetition effect, and the older adults showed a slightly larger 20% repetition effect. The Age × Repetition interaction did not approach significance ($p > .15$). Thus, older adults were not differentially sensitive to repetition, compared with younger adults.

Finally, in order to address whether there was any differential sensitivity across the age groups to the spacing of repetitions, we compared the mean of the massed-presented items (0–lag condition) collapsed across retention interval with the mean of the spaced-presented items (i.e., lags 1, 4, 8, and 20) collapsed across retention interval. The means for the younger adults were 53% and 62% for the massed- and spaced-presented items, respectively, and the means for the older adults were 29% and 34% for the massed- and spaced-presented items, respectively. Thus, the younger adults produced a 9% advantage of spacing and the older adults produced a 5% advantage of spacing. The Age × Spacing interaction again did not reach significance ($p > .10$). Thus, older adults were not less sensitive to the spacing of repetitions, compared with the younger adults.

The Stimulus Fluctuation Model

As noted in the beginning of the article, one of the goals of conducting this experiment was to use a mathematical modeling procedure to isolate age-related changes in variables that presumably play a role in producing the obtained pattern of data. In the present modeling procedure, we have attempted to predict our data from Estes' (1955, 1959) stimulus-fluctuation model. As noted, we have chosen this model because it is mathematically tractable and has been used to account for a wide range of behavioral data (Crowder, 1976). Moreover, it is consistent with the basic thrust of Glenberg's (1976) encoding variability model.

In the following simulation we are attempting to predict four data points for the younger adults and four data points for the older adults. We have selected the lags of 1 and 20 at the short and long retention intervals, respectively, because these points are most relevant to the theory. That is, at lag 1, there should be little evidence of contextual change across time. The massed condition (0 lag) was not selected for the short lag condition because, as was noted earlier, there may be other mechanisms (e.g., attentional satiation) influencing performance when items are repeated on adjacent trials. The long lag of 20 was chosen because this should be the position at which there would be the maximal chance of context fluctuating across time. Moreover, as shown in Figure 1, these four data points produce the theoretically important crossover interaction between lag and retention interval. We now turn to a brief description of the stimulus-fluctuation model.

According to the stimulus-fluctuation model, instead of a stimulus being a single unitary item, it is represented as a population of elements. (In more recent cognitive jargon, elements are akin to the notion of features.) This notion of population of elements can be viewed as consistent with the encoding variability framework described earlier, in that the episodic contextual information ranges from any exteroceptive or interoceptive information that is available to the subject when the to-be-remembered word is presented. For example, consider the word *dog* being presented in an episodic memory experiment. Elements could range from the subject thinking of the name of her own dog to hearing the click of the slide projector presenting the stimulus.

Now, at any given point in time, only a subset of the population of elements is in an available set, whereas the remaining elements are in an unavailable set. Moreover, only those elements that are in the available set have the opportunity to be conditioned or encoded. The only remaining parameter in the model is a fluctuation parameter that suggests that items in the available set randomly exchange across time with items in the unavailable set. For example, at a given moment some sound near the subject may be part of the available set, but as time passes and attention is redirected this sound is no longer available for sampling. In general, when only a short time has passed there is very little exchange between the available and unavailable elements, whereas, with a longer passage of time there is a more complete exchange of elements. This fluctuation parameter is quite consistent with Glenberg's (1976) encoding variability notion that context changes across time.

In order to model the obtained data, it was assumed that there were, on average, 100 elements for a given stimulus situation and that 50 of these elements were in the available set and 50 were in the unavailable set. In this way we allowed only two parameters within the model to vary.[1] These parameters were B, the probability that an element in the available set will be encoded, and F, the rate of fluctuation across time. Both of these parameters were allowed to vary between .01 and .99 in .01 increments. Recall performance in the model is predicted by the percentage of elements in the available set that were encoded. The modeling involved holding either B or F constant at a value and allowing the other parameter to vary. For each combination of B and F values, we calculated the squared deviations between the predicted recall and observed recall for each group of subjects for the critical four data points (i.e., 2 retention intervals × 2 lags).[2] The goal of the modeling was to minimize this squared deviation for each group of subjects.

The predicted and observed data from the best-fitting param-

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[1] It is noteworthy that we did allow the number of elements in the available set to vary between 20 and 80 elements. This third parameter did not increase the predictive power of the model substantially over when we held it constant at 50 elements. Therefore, for simplicity, we simply report the modeling procedure with only two parameters varying.

[2] Note here that for reasons of simplicity and trackability we assumed that the elements either fluctuated (at the 20-lag condition and at the long retention interval) at a given rate or did not fluctuate (at the 1-lag condition and at the short retention interval). A possible extension of the model would be to simulate the data points at the 4-lag and the 8-lag conditions. However, such an enterprise would assume linearly related shifts in fluctuation across lags, and this may not necessarily be the case. Of course, one could increase the precision of the model to accommodate such nonlinear effects by changing the relation between fluctuation

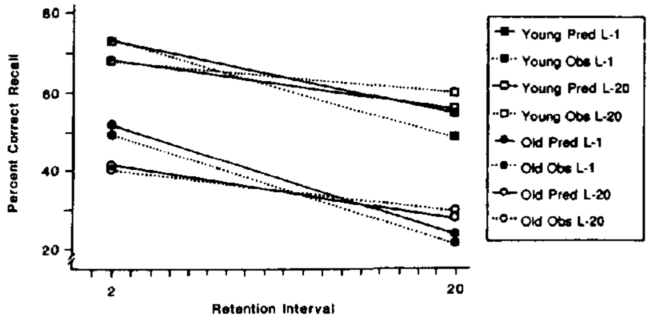

Figure 2. Predicted and observed means as a function of age, retention interval, and lag.

eter estimates are displayed in Figure 2. As shown in Figure 2, the data for the older adults are fit nearly perfectly, with a total absolute deviation for these data points being only 8%. The parameter estimates for this best fit of the older adults are $B = .30$ and $F = .54$. The data for the younger adults are also fit quite nicely at the short retention interval, although at the longer retention interval there is some deviation. The total absolute deviation in this fit is 12%, and the parameter estimates are $B = .50$, and $F = .76$. These results suggest that both the probability of encoding an element in the available set, B, and the rate at which elements fluctuate between the available and unavailable state, F, appear to be lower for the older adults compared with the younger adults. In fact, if one considers percentage change in these parameters, it appears that the older adults encode approximately 60% of the contextual elements that the younger adults encode, and the rate of contextual fluctuation is only 71% as fast for the older adults as for the younger adults. These are clearly substantial changes. Finally, it is noteworthy that this model does an excellent job of accounting for the eight data points by allowing only two parameters to vary. As Crowder (1976) has noted, the crossover interaction between lag and retention interval has been difficult to accommodate within other theoretical frameworks.

General Discussion

The present results have both applied and theoretical implications. First, on a more applied level, these results indicate that older adults' memory is influenced in a similar fashion to that of younger adults by repetition and the spacing of repetitions. Thus, if older adults are interested in retaining information for a relatively long interval, then a useful approach is to space their study time, and it appears that, at least within the limits of the present study, the greater the spacing the better the long-term retention. For example, if an older adult is attempting to learn someone's name, then it appears that an efficient strategy would be to space one's study periods as opposed to extended study at the same point in time. Moreover, if the present account is correct, then it also appears most efficient to change one's context across such study periods.

Although the preceding recommendations seem obvious, we feel they are important because such recommendations for mnemonic techniques based on data from younger subjects do not appear to hold for all variables. For example, on the basis of the levels-of-processing research, one might argue that emphasizing semantic encoding for remembering information might not be as efficient for older adults as for younger adults. That is, it appears that older adults do not benefit as much as younger adults from semantic processing compared with nonsemantic processing (Eysenck, 1974; Simon, 1979). In addition, forming mental images may not be as useful a mnemonic for older adults because there is evidence that older adults do not form images as readily as younger adults (see Canestrari, 1968; Hulicka & Grossman, 1967). In contrast to these observations, the present results clearly indicate that older adults' long-term retention benefits as much from repetitions and increasing lags between repetitions as does that of their younger counterparts.

The present results also have theoretical implications. An attempt was made to model the obtained data by Estes' (1955, 1959) stimulus-fluctuation model to determine what characteristics between the age groups best predicts the obtained difference in performance. The results of this modeling procedure suggested that there is considerable change in both the number of elements that are encoded during stimulus presentation and the rate at which elements fluctuate between available and unavailable states. Thus, on the basis of this model, older adults not only encode less of the contextual information available at a given point in time, as the past research has indicated, but also the contextual information that is important for both encoding and retrieval fluctuates more slowly across time.

It is noteworthy to point out here that the stimulus-fluctuation model that was chosen makes simplifying assumptions regarding (a) the concept of a stimulus event and (b) the likelihood of elements fluctuating between available and unavailable states. First, the stimulus-fluctuation model assumes that a stimulus event involves equally probable elements. It is more likely that some elements have a higher probability of being encoded than other elements. For example, in studying the paired associate, *dog–table,* the possible image of a dog on a table might be a more likely stimulus event to be encoded than would the noise produced by the ventilator in the room. Of course, it is possible that part of the age-related change in memory performance might be due to differences in which elements are available as a function of age. However, the research on semantic priming (Balota & Duchek, 1988) and on simple word associations (Burke & Peters, 1986) suggests that the semantic systems of younger and older adults are very similar. This research suggests that the stimulus set of elements might be the same for the younger and older adults.

The second simplifying assumption that was made regarding the fluctuation parameter is that elements are equally likely to fluctuate between available and unavailable states. This probably is not the case, and in fact, Glenberg (1976) has specifically noted that the stimulus-sampling model would need to be adjusted such that events that are available at time n should be more available at time $n + 1$. This parameter was kept constant in the present modeling procedure because it is unclear why

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and lag. In order to avoid such changes in the power of the model, we simply assumed that fluctuation either did or did not occur at a given rate for the eight most theoretically motivated data points.

this would differentially change as a function of age. Also, because the primary interest was in the crossover interaction between lag and retention interval, there was no need to add a third free-floating parameter that would obviously increase the model's power to predict the current data while sacrificing parsimony.

It should be emphasized here that we are not suggesting that the stimulus-fluctuation model is the only possible account of the present data. In fact, there are a number of alternative models of the spacing effect (see reviews by Crowder, 1976; Hintzman, 1974). Moreover, there may be alternative accounts of the present age-related differences. For example, one simple account might be that older adults, compared with younger adults, are simply less willing to output an item because they are more conservative (see Botwinick, 1984). This account nicely predicts the present pattern of data because the older adults perform precisely as do the younger adults, but only lower. Fortunately, there is a simple way to address this possibility. That is, one could look at the percentage of incorrect trials in which the subjects did not produce any response (i.e., nonresponse trials). If the older adults were simply less likely to output items because they were more conservative then they should produce a higher percentage of nonresponse trials. However, an analysis of the percentage of error trials indicates that there was actually a slightly greater percentage of nonresponse trials for the younger adults (83.6%) than for the older adults (80.6%). Thus, simple conservatism in output does not account for the present results.

Clearly, there may be other alternative accounts of the present pattern of data. For example, one might argue that the present results are somehow related to an age-related change in attentional processes. There are, however, two important aspects of the present data that seem to produce difficulties for such alternative accounts. First, there is the problem of a manipulation (lag) having one effect on memory performance at the long retention interval and the opposite effect on memory performance at the short retention interval. Such a crossover interaction is not very common in the memory literature and, as noted, has been difficult to accommodate within other theoretical frameworks. Second, there is the finding that older and younger adults produce identical patterns of data, even though the younger adults recalled a full 27% more words than did the older adults. Thus, one must have a mechanism(s) within such an alternative account that can change the level of overall performance but not the overall pattern of data. As indicated by the simulation, the stimulus-fluctuation model can accommodate both of these characteristics in the data.

In addition to addressing alternative accounts of the present data, it is necessary to address predictions derived from the present model. We have suggested that the present results can be best accounted for by decreases in both the rate of encoding contextual elements and the rate of fluctuation of contextual elements across time. However, there was no direct manipulation of contextual elements in the present study. There was simply a reliance on (a) a theoretical characterization of the Lag × Retention Interval interaction that emphasizes the notion of contextual encoding and contextual fluctuation, and (b) the argument made by some researchers in the aging literature that younger adults rely more on context than do older adults.

Thus, it is important to more directly influence the parameters in the model. For example, we have suggested that elements may fluctuate from available to unavailable states more slowly in older adults than in younger adults. If the rate of stimulus fluctuation is truly a temporally defined parameter, then it is possible that manipulating the rate of presentation of the materials could modulate this parameter. Thus, increasing the rate of stimulus presentation should decrease the amount of fluctuation between available and unavailable states. In fact, it should be possible to find a presentation rate for the younger adults and a relatively slower presentation rate for the older adults that equates the rate of element fluctuation for the two groups of subjects. This, of course, would be an easily testable aspect of the model.

In addition to influencing the fluctuation parameter, it may also be possible to influence the number of elements encoded. One noteworthy aspect of the present study is that the to-be-remembered stimuli involved associatively *unrelated* paired associates. Such items provide little in the way of contextual support for guiding which elements are encoded. Moreover, there is evidence that older adults have particular difficulty using contextual information when it involves relatively weak associates (e.g., Rabinowitz et al., 1982). It is possible that if associatively *related* contexts are provided, this would guide which elements are encoded for both the young and older adults. This might decrease the age-related difference in the number of elements encoded because both groups of subjects would be more likely to encode the same contextually constrained elements. Thus, manipulations of varying degrees of contextual constraint may provide one approach to influencing the age-related difference in the number of contextual elements encoded.

Summary

The present results are quite clear in producing the predicted crossover interaction between retention interval and lag for both young and older adults. The only difference was that the older adults produced substantially lower overall performance. The results from the modeling procedure suggested that older adults encoded less of the contextual information, consistent with the past literature, and also that the contextual information appears to change more slowly across time for the older adults compared with the younger adults. We believe that without the formalization of the stimulus-fluctuation model, it is unlikely that one would have been led to similar conclusions. Now that this model has been applied to the age-related memory deficit, it is necessary to empirically address more directly the notion of age-related deficits in stimulus encoding and stimulus fluctuation.

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