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Characterizing Adult Age Differences in the Initiation and Organization of Retrieval: A Further Investigation of Retrieval Dynamics in Dual-List Free Recall

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In a recent experiment using dual-list free recall of unrelated word lists, C. N. Wahlheim and M. J. Huff (2015) found that relative to younger adults, older adults showed: (a) impaired recollection of temporal context, (b) a broader pattern of retrieval initiation when recalling from 2 lists, and (c) more intrusions when selectively recalling from 1 of 2 lists. These findings showed older adults' impaired ability to use controlled retrieval to avoid proactive and retroactive interference. In the present investigation, 3 studies examined whether differences in retrieval initiation patterns were unique to aging and whether they were governed by the control mechanisms that underlie individuals' susceptibility to intrusions. In Study 1, we conducted additional analyses of Wahlheim and Huff's data and found that older adults' broader retrieval initiation when recalling 2 lists was a unique effect of age that was not redundant with intrusions made when recalling from individual lists. In Study 2, we replicated these age differences in a dual-list paradigm with semantically associated lists. In Study 3, we found that older adults' broader retrieval initiation generalized when they were given twice the encoding time compared with Study 2. Analyses of transitions between recalls in Studies 2 and 3 showed that older adults used temporal associations less than younger adults, but both groups made similar use of semantic associations. Overall, these findings demonstrate adult age differences in the controlled retrieval of temporal context in hierarchically structured events.

Keywords: aging, cognitive control, free recall, recollection, retrieval dynamics

Older adults have a well-established episodic memory deficit (for reviews, see Balota, Dolan, & Duchek, 2000; Zacks, Hasher, & Li, 2000) that is most apparent in tasks that require self-initiated reinstatement of study context, such as free recall (Craik, 1986). Free recall is a sensitive measure ideal for examining age-related episodic memory deficits because it offers flexible analysis options that can be leveraged to reveal underlying mechanisms. Critically, free recall patterns can reveal differential strategies and contextual dependencies during retrieval (Kahana, 1996). Older adults are also highly susceptible to interference from competing sources of information (Hasher & Zacks, 1988). Thus, one way to understand age-related episodic memory deficits is to examine free recall dynamics in a task that requires recalling from one source while avoiding intrusions from another source.

Wahlheim and Huff (2015) adopted this approach by administering a dual-list free recall procedure to younger and older adults (cf. Unsworth, Brewer, & Spillers, 2013). This allowed for the examination of age differences in the ability to constrain retrieval to a target source under conditions of proactive and retroactive interference. Participants studied two lists of unrelated words and recalled from the first list, the second list, or both lists. When recalling from a single list, older adults recalled fewer target responses and committed more intrusions (cf. Hartley & Walsh, 1980; Kahana, Dolan, Sauder, & Wingfield, 2005; Stine & Wingfield, 1987). A process dissociation procedure (Jacoby, 1991) revealed lower recollection estimates for older adults indicating that a deficit in controlled retrieval impaired their ability to reinstate the target context. In contrast, age invariant estimates of automatic influences indicated that younger and older adults had similar abilities to retrieve information devoid of context. Examination of output dynamics from single-list retrieval conditions showed that older adults were more likely to recall intrusions after target responses and less likely to recall subsequent target responses from adjacent input positions. These results suggested that older adults were impaired in their ability to retrieve contextual information and use that information to cue retrievals of target-list items.

The dual-list free-recall task also provided a unique opportunity to characterize age differences in recall initiation when participants were instructed to recall two lists separated by a distinct context break. These age differences were examined by computing probability of first recall (PFR) curves in the condition where both lists

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were retrieved. PFR curves plot the probability that the first item recalled came from a specific input position from either list and are assumed to describe group differences in retrieval orientation. Figure 1 shows that there were clear profile differences between age groups. Younger adults initiated retrieval mostly from the primacy and recency portions of List 2, whereas older adults initiated their retrieval mostly from the primacy portion of List 1 and the recency portion of List 2. These results suggested that younger adults were more sensitive to the substructure of two distinct lists within a trial, whereas older adults treated the two lists as one longer list. These differences were attributed to older adults' impaired ability to reinstate context, which was the same mechanism posited to underlie their greater intrusions. However, it is unclear whether this difference reflects a unique age difference or whether it is merely a consequence of lower overall memory ability. Moreover, this age difference does not translate to single-list free recall where younger and older adults initiate retrieval similarly (e.g., Howard, Kahana, & Wingfield, 2006; Kahana, Howard, Zaromb, & Wingfield, 2002). Thus, the age differences in recall initiation may be linked to more complex event structures with salient subcontexts (e.g., two distinct lists within a trial).

The primary goal of the present investigation was to address whether age differences in retrieval initiation when recalling from two distinct lists are a unique characteristic of healthy aging or a consequence of differences in recall abilities regardless of age. More important, the notion that differences in retrieval initiation reflect something specific about age rests on two critical assumptions. The first assumption is that age differences in PFR curves do not simply reflect memory impairment. This could occur, for example, if younger and older adults both prefer to retrieve from the end of List 2 because that context is most similar to the test context, but older adults experience more retrieval failures during their initial attempt. When retrieval failures occur, older adults might shift their focus to the first portion of the trial (i.e., List 1 primacy) where items are highly available (cf. Farrell & Lewandowsky, 2002), especially if the context break between lists is not readily retrieved or well encoded. If so, then younger adults with *lower* recall ability would demonstrate the broader retrieval initiation pattern seen in older adults. The second assumption is that these PFR curves do not represent an amalgam of two distinct subgroups of older adults: one that prefers to initiate retrieval at the beginning of List 1 and another that prefers to initiate retrieval at the end of List 2, with the latter potentially showing greater overall recall ability and a pattern of retrieval initiation consistent with younger adults. This would be compatible with the idea that declines in memory ability result in a shift to a more rigid strategy of initiating retrieval from the beginning of List 1. If either of the alternatives described above are correct, then the input position of the first-recalled item would do little if anything to predict age group beyond what would be predicted by overall memory ability. Moreover, these behaviors are quite different from the assumption that a general characteristic of older adults is a highly variable PFR input position across trials.

To determine whether age differences in these retrieval initiation profiles were a unique characteristic of aging, we conducted additional analyses of the data from Wahlheim and Huff (2015). We first compared PFR curves from the condition where both lists were retrieved for subgroups of younger and older adults matched on memory ability. If retrieval initiation patterns only reflect memory ability, then they should be similar for these memory-matched subgroups. In contrast, participants with greater memory ability regardless of age might show the tendency to initiate retrieval from earlier input positions, consistent with the finding that individuals with greater working memory capacity initiate retrieval from earlier positions in single-list free recall (Unsworth & Engle, 2007). If so, then a comparison of younger and older adult groups equated on memory ability should show a *greater* difference in profiles of retrieval initiation. Specifically, relative to their cohort, low performing younger adults would be more likely to initiate retrieval from the most recent positions of List 2 and high performing older adults would be more likely to initiate retrieval from the earliest positions of List 1. This pattern would provide strong evidence that age differences in retrieval initiation are not simply the result of differences in memory ability.

Another goal of the present investigation was to determine whether the observed age differences in PFR curves when recalling from both lists would replicate under conditions that are less conducive of younger adults being sensitive to context differences between lists. We tested this by conducting new experiments using a dual-list free recall procedure that included items with strong associations both within and between lists. The idea was that including between-list associations would result in List 2 items reminding participants of List 1 items (cf. Hintzman, 2010; Jacoby & Wahlheim, 2013); thus, making contextual representations between lists less distinct. This was expected to reduce or even eliminate younger adults' sensitivity to the context break when initiating retrieval from both lists and could potentially cause them to treat both lists as one longer list. However, if older adults still show a broader retrieval initiation pattern in the form of larger List 1 primacy effects, then this would provide strong evidence for age differences in retrieval initiation when recalling from two distinct lists.

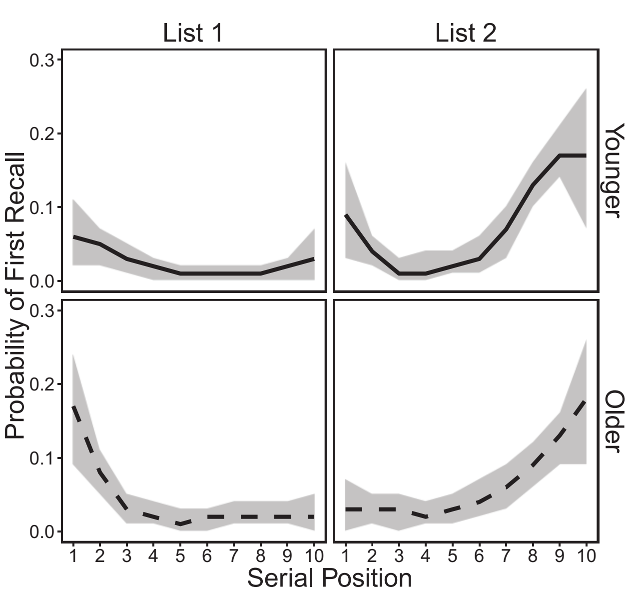

Figure 1. Smoothed probability of first recall curves in the List Both condition from Wahlheim and Huff (2015). Shaded regions are 95% confidence intervals.

To compliment the memory-matching approach, we performed regression-based analyses to seek converging evidence showing that age differences in PFR curves were not because of memory differences. We used hierarchical multiple regression to examine whether the PFR input position uniquely predicted age group when correct recall was included in the same model. More important, this approach did not require discarding participants and enabled more flexible use of covariates. For example, we also considered overall intrusion rates from the single-list conditions to examine the suggestion that a common control mechanism underlies the broader retrieval initiation pattern and higher intrusion rates of older adults. That is, we considered whether PFR behavior and intrusion tendencies were redundant predictors of age groups.

The final goal of the present study was to further characterize age differences in retrieval organization when strong associations are present within and between lists. Research has shown a selective impairment in older adults' recollection of context, and age-invariance in automatic processes under conditions of proactive interference (Jacoby, Debner, & Hay, 2001) and retroactive interference (Jacoby, Bishara, Hessels, & Hughes, 2007). Research has also shown that older adults use temporal associations less than younger adults in free recall, but older adults are equally capable of using semantic associations even when doing so is maladaptive. For example, Golomb, Peelle, Addis, Kahana, and Wingfield (2008) found that younger adults relied less on semantic associations during serial than free recall, but older adults relied on semantic associations similarly in both tasks. This occurred even though using semantic associations in serial recall conflicts with the goal of organizing retrieval using temporal associations.

Based on these findings, we expected greater recollection for younger than older adults, and comparable automaticity for both age groups. This would be consistent with younger adults' advantage in retrieving temporal context diagnostic of list membership. We also expected more within-category recall transitions for exemplars in target lists than for exemplars between target and nontarget lists, indicating use of both temporal and semantic associations. However, we expected this difference to be smaller for older than younger adults because of older adults' recollection deficit. These results would show that older adults' deficit in controlled retrieval diminishes their ability to reinstate temporal context in the service of recalling items from a target source, whereas their intact automatic retrievals preserve their ability to use semantic associations.

Study 1

We first examined whether age differences retrieval initiation from two lists were a unique characteristic of aging by comparing PFR curves for memory-matched subgroups of younger and older adults from Wahlheim and Huff (2015). We briefly summarize the method below before describing our analytic approach and corresponding results and discussion.

Method

The Wahlheim and Huff paradigm included two classes of trials. For some trials, participants studied one 10-item list including unrelated concrete nouns that appeared for 1 s each and completed a multiplication task either before or after studying the list. On other trials, participants studied two 10-item lists of the same sort as above, and these trials were of primary interest here. Participants initiated study of each list by pressing the space bar. This served to differentiate the lists. After study, participants pressed the space bar to begin recalling List 1, List 2, or both lists; retrieval instructions were varied across trials within the experiment.

Results and Discussion

PFR curves smoothed by averaging across three adjacent positions for all except the first and last in each list were examined for the List Both condition. Groups of younger and older adults were split in half ($N = 12$ each) based on mean correct recall across all trial types. Recall did not differ between low performing younger adults ($M = 4.98$, $SD = 0.62$) and high performing older adults ($M = 4.73$, $SD = 0.63$), $t(22) = 0.99$, $p = .33$, $d = 0.41$. Figure 2 shows that age differences in retrieval initiation remained for memory-matched groups (see Figure 2). Younger adults showed large List 2 recency effects, and older adults showed large List 1 primacy effects. This was confirmed by a 2 (Age: Younger vs. Older) × 20 (Position: 1–20) analysis of variance (ANOVA) that revealed a significant Age × Position interaction, $F(19, 418) = 3.17$, $p < .001$, $\eta_p^2 = .13$.

Next, the entire sample was subjected to a hierarchical multiple regression analysis in which the dependent variable was age group (older adults coded 0, younger coded 1). In Step 1, we confirmed the prominent age difference in memory ability, as the recall rate was highly predictive of age group in the expected manner, $t(46) = 6.11$, $p < .001$. In Step 2, the addition of the average PFR position of each participant yielded significance for both the memory ability and PFR variables, *smallest* $t(45) = 4.09$, $p < .001$. This pattern was also obtained when intrusions were used instead of PFR position, showing that memory ability and intrusions were unique predictors of age group, *smallest* $t(45) = -2.31$, $p = .026$.

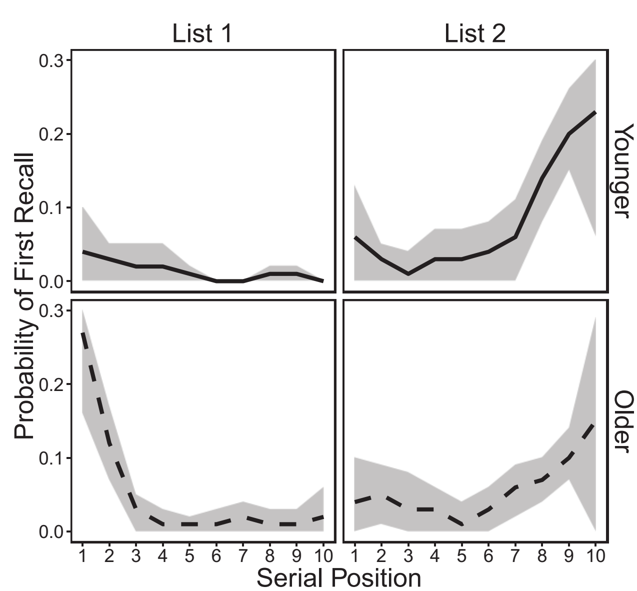

Figure 2. Smoothed probability of first recall curves in the List Both condition from Study 1 with samples from each age group equated on overall memory ability. Shaded regions are 95% confidence intervals.

Finally, Table 1 shows that when combined, all three predictors uniquely predict age group. These analyses demonstrate that PFR behavior and intrusion rates are not redundant with overall memory ability or each other. Both provide unique information in the classification of age groups and PFR behavior is highly sensitive to age-group differences. Indeed, Table 1 suggests that regardless of memory ability or intrusion tendency, a movement of one unit toward the end of the lists in PFR is associated with a 10% increase in the likelihood of being in the younger adult group. Conversely, an analogous movement toward the beginning of the lists yields a 10% increase in the probability of older adult group membership.[1] We replicate and extend the above effects in the next two experiments and address this issue further in the General Discussion.

Study 2

Study 2 examined whether age differences in PFR curves would replicate when the context distinction between lists was diminished by using a variant of the dual-list procedure that included strong semantic associations both within and between lists. Specifically, both lists within a trial included four highly typical and unique exemplars from the same three categories. Between-list associations were included to reduce contextual distinctiveness between lists by encouraging List 1 retrieval during List 2 encoding. Younger adults might appear more similar to older adults by initiating retrieval from both lists as if from one longer list, resulting in lack of List 2 primacy effects. However, if List 1 primacy effects obtain for older but not younger adults, this would provide additional evidence for age differences in retrieval initiation more generally. This would also be bolstered if PFR input position and memory ability both uniquely predict age group. Finally, finding that PFR input position and intrusions both uniquely predict age group would indicate distinct underlying mechanisms.

We also examined the extent to which temporal and semantic associations were used to organize retrieval. We used a process dissociation procedure to verify that older adults' tendency to show lower correct recall and greater intratrial intrusions reflected a selective deficit in recollection. This would suggest that older adults are impaired in their ability to use temporal but not semantic associations. Consequently, both groups should be able to recall subsequent exemplars within categories, but younger adults should better constrain their retrieval to target lists.

Table 1
Full Model Predicting Group Membership: Study 1

Variable	*B*	*SE*	*p*
(Intercept)	.50	.0441	<.001
Correct recall	.01	.0014	<.001
PFR input position	.10	.0248	<.001
Intrusions	−.01	.0062	.023
Observations		48	
R^2/Adjusted R^2		.643/.619	

Note. Age group is the dependent variable (older adults coded 0, and younger adults coded 1). Predictors are mean centered and coefficients indicate the relative increase or decrease in the approximate probability of younger adult group membership with a unit change in the predictor. Correct recall is the summed recall count across all trials. PFR input position reflects the average first recall location across four trials of the both lists recall trials (*range* 1–20). Intrusions are the summed intrusion count across all single-list trials (both intratrial and prior trial intrusions).

Method

Participants. The participants were 36 younger (M_{age} = 19.94 years, *SD* = 2.14, *range* = 18–27) and 24 older (M_{age} = 71.25 years, *SD* = 3.86, *range* = 65–78) adults. Younger adults were recruited from the participant pool at Washington University in St. Louis and were given partial course credit or $10. Older adults were recruited from participant pools maintained by the School of Medicine and the Department of Psychological and Brain Sciences at Washington University in St. Louis and were given $15. Older adults reported significantly more years of education (*M* = 16.29, *SD* = 2.12) than younger adults (*M* = 13.80, *SD* = 1.92), $t(57) = 4.70$, $p < .001$. (One younger adult did not report years of education.) Vocabulary scores on the Shipley Institute of Living Scale (Shipley, 1986) were marginally higher for older (*M* = 35.13, *SD* = 3.33) than younger (*M* = 33.75, *SD* = 2.53) adults, $t(58) = 1.82$, $p = .08$, $d = 0.47$.

Design and materials. A 2 (Age: Younger vs. Older) × 3 (Trial: List 1 vs. List 2 vs. List Both) mixed design was used. Age was a between-subjects variable, and Trial was manipulated within-subjects. The experiment consisted of 12 study-test trials that each included two 12-word study lists followed by a test. The 12 trials comprised four blocks of three trials, with each block containing one from each of the Trial conditions. The presentation order of trial conditions was randomized within blocks. Each 12-word list contained three categories with four exemplars from each category, and the two lists within each trial contained unique exemplars from the same three categories. The presentation order of exemplars in each list was prerandomized such that exemplars from the same category did not appear consecutively. The categories in each trial were unique and no exemplars from those categories appeared on other trials.

Exemplars from 36 categories were taken from the Van Overschelde, Rawson, and Dunlosky (2004) norms (3 categories per trial × 12 trials). Each of the 24 lists in the experiment (2 lists per trial × 12 trials) was matched on exemplar typicality according to

[1] Modeling dichotomous dependent variables via standard regression is known as linear probability modeling and the coefficients can be interpreted as coarse probability estimates. Thus, the coefficients of the model reflect the increase or decrease in the probability of category membership (e.g., young age group) for every unit change of the independent variable. Despite its intuitive parameterization, this approach has been criticized because the residuals of dichotomous variables are not normally distributed and the models can yield predicted scores outside the interval of possible probabilities in certain conditions. To address these concerns one can turn to logistic regression, which requires fewer assumptions than the linear probability model but accordingly is also less powerful and relies on iterative fitting techniques that may fail in small samples. Doing so for the full model of Table 1 again yields significant predictors of overall recall and mean PFR position (*ps* = .008, .020, respectively). However, the intrusion rate only approached significance ($p = .084$). The failure of the intrusion rate to remain reliable likely reflects the reduced power of the logistic modeling approach given this variable was also a less robust predictor than the overall recall and mean PFR variables in the original linear probability model (see Table 1). In situations in which group or category membership percentages are not more extreme than 80 to 20%, linear probability models and logistic regressions usually yield the same conclusions (Cohen, Cohen, West, & Aiken, 2013).

the norms (M = 5.43, SD = 3.44). The two lists in each trial contained the eight most typical exemplars from each category (four per list) that did not belong to more than one category (e.g., exemplars such as "tomato" that belonged to both the fruits and vegetables categories were not included) and were not two-word items (e.g., "boa constrictor" for snake category). The entire stimulus set included 288 total items (4 blocks × 3 trial types × 2 lists × 12 items).

To counterbalance items across Trial conditions, each two-list pair within a trial was first grouped together. List groups were then assigned to sets of three to serve as the three Trial conditions within a block. The assignment of three-group sets to blocks remained constant across all versions of the experiment. However, the assignments of list groups to Trial conditions and lists within a trial to the first and second list positions were rotated across participants, such that each two-list pair served equally often in each Trial condition and each list served equally often in each list position within a trial. This scheme produced six experimental formats.

Procedure. Participants were tested individually. Participants first read an overview of the experiment describing the three different trial conditions and the free recall procedure. Before each trial, participants were told that they would study two lists and that their tasks were to read words aloud and remember them for an upcoming test. Each word appeared for 1 s in the center of the screen followed by a blank screen for 1 s. Participants pressed the space bar to begin studying each list. After study, participants were instructed to recall words in any order from List 1, List 2, or both lists. Participants pressed the space bar to begin recall, and no task intervened between List 2 and recall. Participants had 90 s for recall and were instructed to only report words from the target list(s). Participants pressed the space bar when they made each response. A fixation cross appeared in the middle of the screen and changed colors with space bar presses to signal response registration. An experimenter recorded participants' responses.

Results and Discussion

We first examined age differences in overall recall performance. Next, we decomposed overall performance to: (a) estimate the contributions of recollection and automaticity, (b) characterize retrieval initiation patterns, and (c) examine the use of temporal and semantic associations. Given the larger number of comparisons, we do not systematically report nonsignificant effects or effects qualified by higher order interactions. The level for significance was set at α = .05.

Overall recall performance. Correct recall and intratrial intrusion frequencies (see Table 2) were compared using a 2 (Age: Younger vs. Older) × 2 (Response: Correct Recall vs. Intratrial Intrusion) × 2 (Trial: List 1 vs. List 2) ANOVA. A significant Age × Response interaction, $F(1, 58) = 27.03$, $p < .001$, $\eta_p^2 = .32$ indicated that correct recall was higher for younger (M = 6.15, SD = 1.11) than older (M = 5.26, SD = 1.19) adults, $t(58) = 2.93$, p = .01, d = 0.77, whereas intratrial intrusions were higher for older (M = 2.46, SD = 0.75) than younger (M = 1.54, SD = 0.73) adults, $t(58) = 4.76$, $p < .001$, d = 1.25. These results replicated findings of impaired memory accuracy for older adults.

A significant Age × Trial Type interaction, $F(1, 58) = 8.87$, $p = .004$, $\eta_p^2 = .13$, showed that more responses were output in the List 2 than List 1 condition, and this difference was greater for older (List 2: M = 4.35, SD = 0.85; List 1: M = 3.38, SD = 0.87) than younger (List 2: M = 4.07, SD = 0.67; List 1: M = 3.62, SD = 0.76) adults. Participants may have output more responses in List 2 because List 1 associations primed the accessibility of List 2 items, and this may have occurred to a greater extent for older adults. However, correct recall in the List Both condition (right column) was higher for younger (M = 13.36, SD = 2.86) than older (M = 11.55, SD = 2.77) adults.

Finally, older adults also committed other errors more than younger adults. The average number of each error type was summed across Trial conditions. Prior-trial intrusions were marginally greater for older (M = 0.28, SD = 0.39) than younger (M = 0.13, SD = 0.23) adults, $t(58) = 1.95$, p = .06, d = 0.47; extra-experimental intrusions were numerically greater for older (M = 0.51, SD = 0.40) than younger (M = 0.33, SD = 0.45) adults, $t(58) = 1.62$, p = .11, d = 0.43; repetitions were significantly greater for older (M = 2.03, SD = 2.56) than younger (M = 0.77, SD = 0.62) adults, $t(58) = 2.85$, p = .006, d = 0.68. These results converge in showing that older adults' impaired context reinstatement resulted in more responses from incorrect sources.

Process estimates. Recollection and automaticity were estimated using process dissociation equations (Jacoby, 1991). Only correct recalls and intratrial intrusions were entered into the model to approximate dual-list procedures used in recognition memory (e.g., Yonelinas, 1994) and to limit the number of possible responses. The model assumes that correct recall occurred when a word was recollected (R) or came to mind automatically (A) when recollection failed A(1-R): Correct Recall = R + A(1-R). The model also assumes that an intratrial intrusion occurred when a word came to mind automatically and participants failed to recollect that it came from a nontarget list A(1-R): Intratrial Intrusion =

Table 2
Response Frequencies Per Trial as a Function of Age, Response, and Trial: Studies 2 and 3

			Trial		
Study	Age	Response	List 1	List 2	List Both
Study 2	Younger	Correct recall	5.96 (.47)	6.34 (.36)	13.36 (.97)
		Intratrial intrusions	1.28 (.22)	1.80 (.33)	—
	Older	Correct recall	4.73 (.66)	5.80 (.49)	11.55 (1.17)
		Intratrial intrusions	2.02 (.37)	2.91 (.41)	—
Study 3	Older	Correct recall	4.89 (.64)	5.26 (.58)	11.57 (1.47)
		Intratrial intrusions	2.24 (.48)	3.07 (.51)	—

Note. Margins of error for 95% confidence intervals are displayed in parentheses.

A(1-R). Recollection was estimated as the probability of correct recall minus intratrial intrusions: R = Correct Recall—Intratrial Intrusion. Automaticity was then estimated using algebra: A = Intratrial Intrusion/(1-R). Estimates of recollection and automaticity were calculated separately for the List 1 and List 2 conditions.

Process estimates (see Table 3) were compared using separate 2 (Age: Younger vs. Older) × 2 (List: 1 vs. 2) ANOVAs for recollection and automaticity. Recollection estimates revealed a significant effect of Age, $F(1, 57) = 25.48$, $p < .001$, $\eta_p^2 = .31$, showing greater estimates for younger ($M = .38$, $SD = .11$) than older ($M = .23$, $SD = .10$) adults. In contrast, automaticity estimates revealed a significant effect of Age, $F(1, 57) = 8.37$, $p = .005$, $\eta_p^2 = .13$, showing greater estimates for older ($M = .27$, $SD = .07$) than younger ($M = .21$, $SD = .08$) adults, $F(1, 57) = 8.37$, $p = .005$, $\eta_p^2 = .13$. A significant effect of List also indicated that automaticity was higher for List 2 ($M = .27$, $SD = .10$) than List 1 ($M = .20$, $SD = .08$), $p < .001$, $\eta_p^2 = .47$.

These results suggest that older adults were impaired in their recollection of temporal context and were more likely to report items devoid of specific list context. The inverse relationship between recollection and automaticity between age groups suggested that participants used both direct retrieval and generate-recognize strategies that emphasize preretrieval context reinstatement and postretrieval monitoring, respectively (cf. Hunt, Smith, & Toth, 2016). Consequently, older adults' recollection deficit likely impaired both of these processes. We examined whether the inverse relationship between recollection and automaticity across age groups was because of an artifact of the model by computing correlations between processes estimates for each condition within age groups. Results revealed limited support for the idea that this relationship was merely an artifact as there was only one significant negative association, $r = -.40$, $p = .02$, which occurred in the List 2 condition for younger adults.

Retrieval initiation. Smoothed PFR curves were first compared between age groups in the single-list conditions (see Figure 3) using separate 2 (Age: Younger vs. Older) × 12 (Position: 1–12) ANOVAs for each single list condition. Figure 3 (left panel) shows List 1 primacy effects that were confirmed by a significant effect of Position, $F(11, 638) = 31.69$, $p < .001$, $\eta_p^2 = .35$. A significant Age × Position interaction, $F(11, 638) = 2.09$, $p = .02$, $\eta_p^2 = .04$, also showed that older adults initiated retrieval from earlier positions than younger adults. This unexpected pattern may have resulted from younger adults being reminded of earlier exemplars more often during study, which blended contextual representations further across early input positions. Figure 3 (right panel) shows List 2 recency effects that were confirmed by a significant effect of Position, $F(11, 638) = 96.22$, $p < .001$, $\eta_p^2 = .62$. The Age × Position interaction was not significant, $F(11, 638) = 1.03$, $p = .42$, $\eta_p^2 = .02$. Overall, these results are consistent with previous comparisons of PFR curves showing primacy effects on delayed tests and recency effects on immediate tests for younger and older adults (e.g., Kahana et al., 2002).

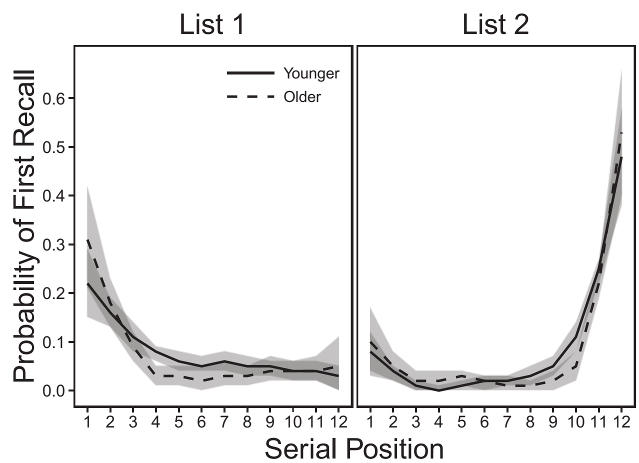

Figure 3. Smoothed probability of first recall curves in the List 1 condition (left panel) and List 2 condition (right panel) as a function of age and serial (input) position in Study 2. Shaded regions are 95% confidence intervals.

Smoothed PFR curves were next compared between age groups in the List Both condition (see Figure 4) using 2 (Age: Younger vs. Older) × 24 (Position: 1–24) ANOVAs. Figure 4 (top panels) shows age differences in patterns of initiation for the entire sample of participants. A significant Age × Position interaction, $F(23, 1334) = 2.92$, $p < .001$, $\eta_p^2 = .05$, revealed larger List 1 primacy effects for older than younger adults and larger List 2 recency effects for younger than older adults. In contrast to earlier findings, younger adults did not show List 2 primacy effects presumably because between-list associations made context representations for each list less distinct. These patterns provide strong evidence for age differences in retrieval initiation from hierarchically structured lists.

To determine whether these patterns could be explained by differences in memory ability, PFR curves were compared for subsamples of younger and older adults equated on correct recall. Participants were first rank ordered within age groups based on correct recall. Because the samples of younger and older adults were different sizes, the top 12 older adults were compared with 12 adjacent younger adults whose mean was closest to older adults. Correct recall did not differ between younger ($M = 8.66$, $SD = 0.40$) and older ($M = 8.61$, $SD = 0.78$) adults, $t(22) = 0.19$, $p = .85$, $d = 0.08$. Figure 4 (bottom panels) shows that age differences in patterns of retrieval initiation were again obtained, despite there being no difference in memory ability. A 2 (Age: Younger vs. Older) × 24 (Position: 1–24) ANOVA revealed a significant Age × Position interaction, $F(23, 506) = 1.74$, $p = .02$, $\eta_p^2 = .07$, showing greater List 1 primacy for older adults, and greater List 2 recency for younger adults.

The unique predictive value of PFR behavior was again confirmed using the full sample and hierarchical regression (older

Table 3
Process Estimates as a Function of Age and Trial: Studies 2 and 3

Study	Age	Recollection		Automaticity	
		List 1	List 2	List 1	List 2
Study 2	Younger	.39 (.05)	.37 (.04)	.18 (.03)	.24 (.03)
	Older	.23 (.06)	.24 (.05)	.22 (.03)	.32 (.04)
Study 3	Older	.22 (.07)	.18 (.05)	.23 (.04)	.31 (.04)

Note. Margins of error for 95% confidence intervals are displayed in parentheses.

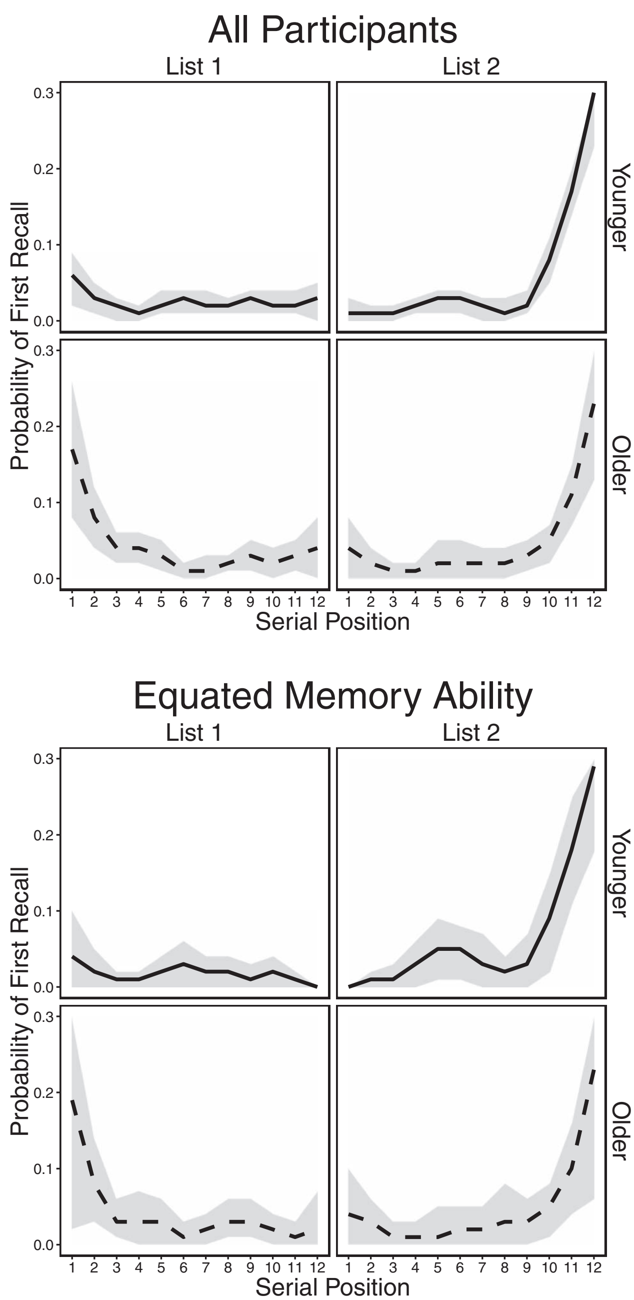

Figure 4. Smoothed probability of first recall curves in the List Both condition from Study 2 for all participants (top panels) and from samples from each age group equated on overall memory ability (bottom panels). Shaded regions are 95% confidence intervals.

adults coded 0, younger coded 1). In Step 1, we confirmed a prominent age-related deficit in memory ability, and indeed the recall rate predicted age group in the expected fashion, $t(58) = 2.82$, $p = .007$. In Step 2, the average PFR position was added and this yielded significance for the memory ability and PFR variables, *smallest* $t(57) = 3.29$, $p = .002$. This pattern repeated when the intrusion rate was used instead of average PFR position, showing that memory ability and intrusion rates were unique predictors of age group, *smallest* $t(57) = 2.55$, $p = .013$. Finally, Table 4 shows that when combined, memory ability, average PFR, and intrusion rates all uniquely predicted age group.[2] These analyses replicate the findings in the extant data, demonstrating that PFR behavior and intrusion rates are not simply redundant with poor overall memory ability or each other.

Output organization. The use of temporal and semantic associations was examined by comparing transition probabilities within categories that occurred within and between lists (see Table 5). Within-list transitions occurred when subsequent responses from the same category were from the target list, whereas Between-list transitions occurred when subsequent responses from the same category were from different lists. Between-list transitions in the single-list conditions were transitions between correct recalls and intratrial intrusions (in either order), whereas the same transitions in the List Both condition were between correct recalls from different lists. The extent to which participants used temporal associations in conjunction with semantic associations was indexed as the difference between within- and between-list transition probabilities in the single-list conditions. Higher within-list probabilities indicate an ability to focus retrieval to one temporal context (list) while simultaneously exploiting the utility of preexisting associations and avoiding recall of associated words from nontarget lists. In contrast, higher between-list probabilities in the single-list conditions indicate a diminished ability to constrain retrieval to the appropriate temporal context and greater reliance on semantic associations.

Single-list conditions were examined using a 2 (Age: Younger vs. Older) × 2 (Transition: Within- vs. Between-List) × 2 (List: 1 vs. 2) ANOVA. A significant Age × Transition interaction, $F(1, 58) = 20.25$, $p < .001$, $\eta_p^2 = .26$, showed that the difference between within- and between-list transitions was greater for younger than older adults. In fact, within-list transitions were significantly greater for younger ($M = .28$, $SD = .09$) than older ($M = .23$, $SD = .08$) adults, $t(58) = 2.43$, $p = .02$, $d = 0.65$, whereas between-list transitions were significantly greater for older ($M = .19$, $SD = .06$) than younger ($M = .12$, $SD = .06$) adults, $t(58) = 4.52$, $p < .001$, $d = 1.19$. This showed that younger adults used temporal associations more effectively than older adults. There was also a significant Transition × List interaction, $F(1, 58) = 7.40$, $p = .009$, $\eta_p^2 = .11$, showing that for both age groups, within-list transitions were significantly greater for List 1 ($M = .29$, $SD = .10$) than for List 2 ($M = .23$, $SD = .11$), $t(59) = 3.89$, $p < .001$, $d = .55$, which resulted from higher intrusion rates in List 2, whereas between-list transitions did not differ between List 1 ($M = .15$, $SD = .08$) and List 2 ($M = .15$, $SD = .08$), $t(59) = .46$, $p = .65$, $d = .07$.

The difference between within- and between-list transitions for the List Both condition also indexed the use of temporal and semantic associations. However, the retrieval demands of that condition allowed participants to broaden their focus to the context of the entire trial. Thus, we expected higher probabilities for between- than within-list transitions as participants could base

[2] Applying logistic regression instead of the linear probability model to these data yielded the same conclusions with all three predictors remaining reliable and in the same direction for overall recall, mean PFR position, and intrusion rates (*ps* = .009, .021, and .002).

Table 4
Full Model Predicting Group Membership: Study 2

Variable	*B*	*SE*	*p*
(Intercept)	.60	.0512	<.001
Correct recall	.01	.0025	.004
PFR input position	.05	.0206	.014
Intrusions	−.03	.0072	<.001
Observations		60	
R^2/Adjusted R^2		.424/.394	

Note. Age group is the dependent variable (older adults coded 0, and younger adults coded 1). Predictors are mean centered and coefficients indicate the relative increase or decrease in the approximate probability of younger adult group membership with a unit change in the predictor. Correct recall is the summed recall count across all trials. PFR input position reflects the average first recall location across four trials of the List Both trials (*range* 1–24). Intrusions are the summed intrusion count across all single-list trials (both intratrial and prior trial intrusions).

their retrieval primarily on the semantic associations unique to each trial.

The List Both condition was examined using a 2 (Age: Younger vs. Older) × 2 (Transition: Within- vs. Between-List) × 2 (List: 1 vs. 2) ANOVA. A significant effect of Transition, $F(1, 58) = 24.13$, $p < .001$, $\eta_p^2 = .29$, showed higher probabilities for between-list ($M = .33$, $SD = .08$) than within-list ($M = .27$, $SD = .08$) transitions. In addition, a significant Age × List interaction, $F(1, 58) = 5.21$, $p = .03$, $\eta_p^2 = .08$, showed that younger adults' between-list transition probabilities trended toward being greater for List 1 than List 2, whereas older adults' probabilities did not differ between lists, but the reason for this is unclear.

Overall, the results from the single-list conditions showed impairment in older adults' ability to constrain retrieval to a specific context and maintain that representation throughout recall when faced with competition from associated responses in another list. In addition, the results from the dual-list conditions showed that both age groups could similarly constrain their retrieval to the trial as a whole as a result of unique categories being included on each trial. However, these similar behaviors may have differed subjectively between age groups as younger adults likely had better access to contextual features despite the limited need to constrain their retrieval using those features.

Study 3

Study 3 examined the generalizability of age differences in PFR curves when recalling from two lists. One possible explanation for the obtained differences is that short study durations did not allow older adults to sufficiently process items during encoding because of their slower processing speed (cf. Salthouse, 1996). In combination with their lower working memory capacity, this could have caused older adults to forget recency items more rapidly than younger adults. We examined this possibility by testing new participants in the Study 2 procedure with double the study time. Finding that older adults still show the broad retrieval initiation pattern in the List Both condition would provide evidence against an insufficient encoding account. As in prior experiments, we also examined: (a) contributions of recollection and automaticity, (b) how PFR curves relate to memory ability and intrusions, and (c) category transitions that assess reliance on temporal and semantic associations.

Method

Participants. The participants were 24 older adults recruited through the Washington University School of Medicine who were paid $15. Age ($M_{Age} = 72.65$ years, $SD = 5.96$, *range* = 65–89); years of education ($M = 15.67$, $SD = 1.88$); and vocabulary scores ($M = 35.13$, $SD = 3.04$) did not differ from Study 2, *largest* $t(46) = 1.08$, $p = .29$, $d = 0.31$.

Design, materials, and procedure. The details in Study 3 were identical to Study 2, except that the study duration was 2 s.

Results and Discussion

The primary purpose of the following analyses was to determine whether patterns of results from Study 3 differed from those in Study 2. Thus, we only report the outcomes of comparisons that determine whether the results from Study 3 replicated those from Study 2.

Overall recall performance. The single-list conditions from Studies 2 and 3 (Table 2, middle and bottom rows) were compared using a 2 (Study: 2 vs. 3) × 2 (Response: Correct Recall vs. Intratrial Intrusion) × 2 (Trial: List 1 vs. List 2) ANOVA. The Study × Response × Trial interaction was not significant, $F(1, 46) = 1.47$, $p = .23$, $\eta_p^2 = .03$, indicating that the patterns did not differ between studies.

Process estimates. Process estimates (Table 3, middle and bottom rows) were compared using separate 2 (Study: 2 vs. 3) × 2 (Trial: List 1 vs. List 2) ANOVAs for recollection and automaticity. The Study × Trial interactions were not significant, *largest* $F(1, 46) = 1.50$, $p = .23$, $\eta_p^2 = .03$. In addition, correlations between recollection and automaticity within age groups in each condition revealed one marginally significant negative association, $r = -.37$, $p = .08$.

Retrieval initiation. Smoothed PFR curves in the single-list conditions (Figure 5, top panels) were compared using separate 2 (Study: 2 vs. 3) × 12 (Position: 1–12) ANOVAs. The Study × Position interactions were not significant, *largest* $F(11, 506) = 1.54$, $p = .11$, $\eta_p^2 = .03$, indicating no differences in List 1 primacy or List 2 recency effects between studies. Smoothed PFR curves in the List Both condition (Figure 5, bottom panels) were compared using a 2 (Study: 2 vs. 3) × 24 (Position: 1–24) ANOVA. The Study × Position interaction was not significant, $F(23, 1058) =$

Table 5
Category Transition Probabilities as a Function of Age, Transition, and Trial: Studies 2 and 3

			Single-list		List both	
Study	Age	Transition	List 1	List 2	List 1	List 2
Study 2	Younger	Within-list	.31 (.03)	.25 (.04)	.30 (.03)	.24 (.04)
		Between-list	.12 (.03)	.13 (.02)	.34 (.03)	.31 (.03)
	Older	Within-list	.25 (.05)	.21 (.04)	.26 (.03)	.25 (.04)
		Between-list	.19 (.03)	.19 (.04)	.34 (.05)	.35 (.05)
Study 3	Older	Within-list	.27 (.04)	.21 (.03)	.30 (.04)	.27 (.05)
		Between-list	.19 (.05)	.20 (.03)	.36 (.06)	.34 (.04)

Note. Margins of error for 95% confidence intervals are displayed in parentheses.

0.75, $p = .79$, $\eta_p^2 = .02$, showing the same broad pattern of retrieval initiation in both studies.

We again used hierarchical regression to confirm that differences in memory ability were insufficient to explain age differences in retrieval initiation patterns. We did this by comparing the Study 3 older adults with the Study 2 younger adults. Memory ability again predicted age group, $t(58) = 2.83$, $p = .006$, and adding PFR position resulted in significance for both variables, *smallest* $t(57) = 2.93$, $p = .005$. The pattern repeated when intrusion rates were substituted for PFR position, *smallest* $t(57) = 2.66$, $p = .01$, and when all three variables were included (general memory, average PFR, and intrusion rates) they all reliably predicted age group (see Table 6).[3]

Output organization. Category transitions (see Table 5) were compared using separate 2 (Study: 2 vs. 3) × 2 (Transition: Within- vs. Between-List) × 2 (List: 1 vs. 2) ANOVAs for the single-list and List Both conditions. The Study × Transition × List interaction were not significant, *largest* $F(1, 46) = .28$, $p = .60$, $\eta_p^2 < .01$, showing no difference in retrieval organization between studies.

General Discussion

The present investigation further examined age differences in the initiation and organization of retrieval in dual-list free recall. Age differences in retrieval initiation occurred when participants recalled from two distinct lists nested within a larger retrieval context: Younger adults showed List 2 recency effects, whereas older adults showed List 1 primacy and List 2 recency effects. This pattern generalized across materials and study durations and was not because of differences in memory ability nor was it redundant

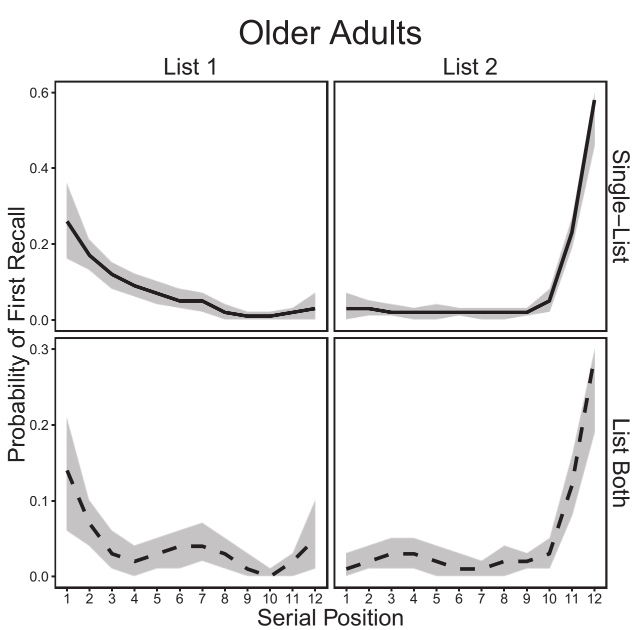

Figure 5. Smoothed probability of first recall curves for the older adults in Study 3. The Single-list conditions are displayed in the top panels and the List Both condition is displayed in the bottom panels. Shaded regions are 95% confidence intervals.

Table 6
Full Model Predicting Group Membership: Study 2 (Younger Adults) Versus Study 3 (Older Adults)

Variable	*B*	*SE*	*p*
(Intercept)	.60	.0485	<.001
Correct recall	.01	.0022	.004
PFR input position	.06	.0223	.008
Intrusions	−.03	.0057	<.001
Observations		60	
R^2/Adjusted R^2		.450/.421	

Note. Age group is the dependent variable (older adults coded 0, and younger adults coded 1). Predictors are mean centered and coefficients indicate the relative increase or decrease in the approximate probability of younger adult group membership with a unit change in the predictor. Correct recall is the summed recall count across all trials. PFR input position reflects the average first recall location across four trials of the List Both trials (*range* 1–24). Intrusions are the summed intrusion count across all single-list trials (both intratrial and prior trial intrusions).

with differences in intrusion rates. Older adults relied less on recollection and more on automaticity, indicating impaired use of temporal associations and intact use of semantic associations. Converging evidence was obtained as category transitions in single-list conditions were made within target lists more than between target and nontarget lists, and this difference was greater for younger than older adults. We discuss the implications of these findings below.

Retrieval Initiation

Investigations of age differences in single-list free recall have consistently shown age-related impairments (e.g., Craik, 1968; Hultsch, 1969; Schonfield & Robertson, 1966). However, younger and older adults show identical retrieval initiation patterns (e.g., Healey & Kahana, 2016; Kahana et al., 2002; Wahlheim & Huff, 2015). Specifically, participants initiate retrieval from recency positions on immediate tests and primacy positions on delayed tests. The results from Study 2 replicated those effects, with the exception that the primacy effects in the List 1 condition (a delayed test) were slightly larger for older than younger adults. The main difference in the present study was that lists included semantically associated items, whereas earlier studies used unrelated lists. One explanation is that younger adults rehearsed primacy items more because semantic associations elicited more study-phase retrievals, which extended temporal associations across more items.

These findings indicate that both age groups initiated retrieval similarly under conditions of proactive and retroactive interference. However, this requires reconciliation with the notion that older adults' recollection deficit impairs their ability to reinstate study context and avoid interference (cf. Hay & Jacoby, 1999; Jacoby, 1999; Jacoby, Kelley, & McElree, 1999). To illustrate this point, higher working memory capacity predicts earlier staring positions for younger adults, presumably because participants can

[3] Applying logistic regression instead of the linear probability model to these data yielded the same conclusions with all three predictors remaining reliable and in the same direction for overall recall, mean PFR position, and intrusion rates ($ps = .007$, .007, and $< .001$).

maintain access to more recency items (Unsworth & Engle, 2007). However, younger and older adults show similar retrieval initiation patterns in other studies, despite older adults' lower working memory capacity (e.g., Park et al., 2002). This discrepancy suggests that the shapes of PFR curves are insensitive to age-related recollection deficits. Instead, these deficits may manifest in the probability of correct recall on the first retrieval attempt. To examine this, we compared correct recall for first-recalled items collapsed across single-list conditions in Study 2 and found significantly higher accuracy for younger (M = .95, SD = .06) than older (M = .89, SD = .13) adults, $F(1, 58) = 6.95$, $p = .01$, $\eta_p^2 = .11$. This suggests that older adults' recollection deficit impairs their ability to initially reinstate target context, but when successful, both groups recall the most accessible items in a similar manner. This similarity may indicate a role for preserved automaticity in older adults.

In the present investigation, we examined whether the age differences in the shape of PFR curves occur when participants recalled from two lists separated by a clear break in context and when retrieval conditions were varied throughout the experiment. Our interest in patterns of retrieval initiation when recalling from two lists was motivated by the idea that the hierarchical structure of a trial with two subordinate lists could potentially elicit differences in the breadth of retrieval orientation. Specifically, we thought younger adults would treat lists within a trial as separate units, whereas older adults would treat both lists as one larger unit. This hypothesis was based on the notions that individuals with impaired executive control show a broader focus of retrieval (e.g., Burgess & Shallice, 1996; Morcom, 2016), and that older adults represent hierarchically structured events at coarser grains than younger adults (e.g., Kurby & Zacks, 2011; Zacks, Speer, Vettel, & Jacoby, 2006). Consistent with this, PFR curves showed List 1 primacy and List 2 recency for older adults and List 2 recency for younger adults. This occurred because older adults vacillated between these positions across trials, whereas younger adults more consistently initiated retrieval from the end of List 2. This difference was exaggerated when age groups were matched on memory ability and was not redundant with older adults' greater susceptibility to intrusions.

Older adults may have vacillated between List 1 primacy and List 2 recency when initiating retrieval from both lists as a consequence having shifted between these strategies across different single-list trials. This possibility has implications for theories of age differences in the strategic control of memory and could potentially inform remembering in naturalistic contexts. Theoretically, older adults' attempts at various retrieval strategies could indicate an intact ability to flexibly control retrieval initiation from hierarchically structured events. Consistent with this, older adults have an intact ability to initiate retrieval from the first input position in immediate serial recall (e.g., Golomb et al., 2008). Another possibility is that older adults' vacillation across trials may arise from retrieval strategies perseverating across trials. A final possibility is that instructions to recall from both lists somehow eliminates recency items from working memory to a greater extent for older than younger adults. This could be tested in future studies by determining whether older adults can consistently initiate retrieval from the end of List 2 if instructed to do so when recalling from both lists. More generally, consideration of age differences in retrieval initiation could illuminate the mechanisms underlying retrieval of hierarchically structured events and inform theories of event perception (e.g., Zacks, Speer, Swallow, Braver, & Reynolds, 2007) and attempts to remediate age-related deficits in the ability to comprehend and remember naturalistic activities.

Output Organization

A benefit of including semantic associations in dual-list free recall is that it allows for examination of the use of temporal and semantic associations in retrieval organization. Earlier single-list free recall studies with unrelated word lists showed age-related impairment in retrieval of temporal context, as older adults were less likely to successively recall target items from adjacent input positions (e.g., Healey & Kahana, 2016; Kahana et al., 2002; Wahlheim & Huff, 2015; Zaromb et al., 2006). Additional evidence for impaired use of temporal associations has also been shown in dual-list free recall as older adults recall fewer successive target list items regardless of input position when recalling from one of two lists (Wahlheim & Huff, 2015). In contrast, older adults have shown intact use of semantic associations in cluster-based analyses (e.g., Golomb et al., 2008; Wingfield & Kahana, 2002). Together, these results suggest that temporal associations should override semantic associations when retrieving from single lists in dual-list free recall to a greater extent for younger than older adults.

The results from the single-list conditions in Study 2 showed that participants recalled subsequent exemplars from the same categories within target lists more often than between target and nontarget lists, and this difference was greater for younger than older adults. These results indicated an age-related deficit in controlled retrieval of temporal context. Given that older adults recalled fewer first-retrieved items correctly, the quality of retrieved context elicited on their first retrieval attempt was likely diminished, which impaired their ability to cue subsequent target-list retrievals and monitor the source of retrieved items. Consequently, older adults may have shown a greater willingness to report retrievals devoid of context because the semantic associations with target-list items increased the perceived likelihood that they were correct. This explanation is compatible with the finding that older adults relied on recollection less and automaticity more than younger adults.

These findings have theoretical implications as only one prior study has suggested that older adults' impairment in free recall reflects a recollection deficit with preserved automaticity (Wahlheim & Huff, 2015). This suggestion is partially compatible with a computational model of age differences in free recall proposing that older adults are impaired in their ability to reinstate and monitor the context associated with recalled items (Healey & Kahana, 2016). However, this model does not explain how the ability to retrieve items devoid of context is preserved for older adults and how this might interact with qualitative differences in the bases for reporting, even though it can account for differences in recognition false alarms by making assumptions similar to those held by dual process models. Consideration of qualitatively distinct bases for reporting is critical given that recollection deficits create a negative cascade of effects on the accuracy of postretrieval monitoring and reporting decisions (Kelley & Sahakyan, 2003). One possibility is that when items are retrieved automatically, older adults consider strength as a more valid cue because they have a longer history of being reinforced for successful retrievals devoid of context. Future modeling efforts could benefit from incorporating theoretical accounts of the interaction between metacognitive monitoring and control processes (e.g., Koriat & Goldsmith, 1996; Koriat, Ma'ayan, & Nussinson, 2006; Nelson & Narens, 1990).

Conclusion

The present investigation showed that older adults engaged a more variable retrieval strategy than younger adults when recalling from distinct lists. Older adults were also impaired in their abilities to initiate, evaluate, and report their retrievals from individual lists. These results suggest that older adults represent and reinstate the context associated with hierarchically structured events in a different manner than younger adults. Further research aimed at the generalizability and boundary conditions of these differences may reveal a critical role for strategically controlled retrieval initiation. Variants of the dual-list free recall procedure may have the potential to provide controlled tests of how individuals initiate and organize retrieval of naturalistic activities that contain hierarchically structured, sequentially dependent events.

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