Age differences in the focus of retrieval: Evidence from dual-list free recall

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Abstract:

In the present experiment, we examined age differences in the focus of retrieval using a dual-list free recall paradigm. Younger and older adults studied 2 lists of unrelated words and recalled from the first list, the second list, or both lists. Older adults showed impaired use of control processes to recall items correctly from a target list and prevent intrusions. This pattern reflected a deficit in recollection verified using a process dissociation procedure. We examined the consequences of an age-related deficit in control processes on the focus of retrieval using measures of temporal organization. Evidence that older adults engaged a broader focus of retrieval than younger adults was shown clearly when participants were instructed to recall from both lists. First-recalled items originated from more distant positions across lists for older adults. We interpret older adults' broader retrieval orientation as consistent with their impaired ability to elaborate cues to constrain retrieval. These findings show that age-related deficits in control processes impair context reinstatement and the subsequent focus of retrieval to target episodes.

Keywords: aging | cognitive control | interference | free recall | recollection

Article:

A common complaint by older adults is difficulty remembering recently experienced events. Older adults have a well-established episodic memory deficit that has been shown in a variety of laboratory tasks (for reviews, see Balota, Dolan, & Duchek, 2000; Hoyer & Verhaeghen, 2006; Zacks, Hasher, & Li, 2000). A prominent characteristic of this deficit is that older adults are impaired in their ability to retrieve information from a target source while avoiding competition from irrelevant sources (Hasher & Zacks, 1988). The ability to constrain retrieval to a particular source is critical for counteracting the deleterious effects of interference. Older adults' greater susceptibility to interference has been attributed to a deficiency in their use of controlled processing, such as recollection, to constrain retrieval (Hay & Jacoby, 1999; Jacoby, 1999). In the present experiment, we sought to examine the consequences of age-related deficits in controlled processing on the focus of retrieval in free recall. Here, we deployed a dual-list free recall procedure to assess age differences in the contribution of controlled processes at retrieval and to leverage measures of output order to characterize age differences in the breadth of focus during retrieval.

We examined the role of controlled processing in age differences in episodic memory using a free-recall task because it places high demands on self-initiated reinstatement of contextual information. This aspect of free recall makes it particularly sensitive to age differences because older adults are most impaired on tasks that require self-generation of retrieval cues (Craik, 1986). Here, we used a dual-list free recall paradigm in which participants studied two lists of words and were told to recall from the first list, the second list, or both lists. We chose this paradigm because it allowed us to estimate the contributions of controlled and automatic processes to recall performance using a process dissociation procedure. In addition, it allowed us to examine participants' focus of retrieval when they were instructed to retrieve from sets of varying sizes and temporal distances from the recall period. Finally, it allowed us to analyze various aspects of retrieval dynamics to more completely characterize the effects of age differences in context reinstatement on the focus of retrieval.

Process Dissociation: Controlled and Automatic Influences

An advantage of using a dual-list free recall paradigm when examining age differences in episodic memory is that this paradigm allows for estimation of the contribution of controlled and automatic forms of memory. Recollection is held to be a form of cognitive control that restricts retrieval to a target source (Jacoby, 1999). Importantly, estimates of recollection may reflect the ability to reinstate a previously experienced context, which allows individuals to differentiate between items from target and nontarget sources. In contrast, information brought to mind by automatic influences arrives without conscious awareness of its origin. The contributions of recollection and automaticity can be estimated by comparing performance in a condition in which the two processes work in concert to produce the same response to a condition in which the two processes work in opposition to produce different responses. In a dual-list paradigm, recollection and automaticity operate in tandem to produce responses from a target list, whereas recollection works in opposition to automaticity to prevent intrusions from an interfering list.

Studies using process dissociation procedures have shown that older adults have a selective deficit in controlled processing with preserved automaticity in recognition and cued recall tasks. In recognition, age-related recollection deficits often take the form of older adults endorsing fewer responses from target lists (hits) and more responses from nontarget lists (false alarms) relative to younger adults (e.g., Jacoby, 1999). In cued recall, these deficits often take the form of older adults recalling fewer correct responses from target lists and producing more intrusions from interfering lists relative to younger adults (e.g., Hay & Jacoby, 1999; Jacoby, Debner, & Hay, 2001). Given the consistency across tasks, one could expect older adults to produce fewer correct responses and more intrusions in a dual-list free recall paradigm when the task is to recall from only one list. However, to our knowledge, no previous studies have examined whether an age-related recollection deficit exists in free recall. Finding such a deficit in a dual-list recall paradigm would suggest that age-related deficits in controlled processes contribute to impairments in context reinstatement and the focus of retrieval.

Deconstructing Free Recall: Retrieval Dynamics

Examining age differences in dual-list free recall also allows for analyses that assess various aspects of retrieval processes. Howard and Kahana (1999) suggested that the contribution of different aspects of retrieval to single-list free recall could be examined by deconstructing performance based on retrieval dynamics. This approach to analyzing free recall provides information beyond that obtained from analyses of serial position curves (Murdock, 1962), which are difficult to interpret because they reflect joint influences of encoding and retrieval processes. The manner of recall initiation can be assessed by computing probability of first recall (PFR) curves. PFR curves plot the probability of first-recalled items as a function of the input position during study. PFR curves on immediate tests show recency effects that reflect recall being initiated by offloading items from primary memory. PFR curves on delayed tests show primacy effects that reflect the most efficiently encoded items being recalled first when items from primary memory are less accessible. Younger and older adults tend to initiate recall similarly in that both show comparable recency effects on immediate tests and primacy effects on delayed tests (e.g., Golomb, Peelle, Addis, Kahana, & Wingfield, 2008; Kahana, Howard, Zaromb, & Wingfield, 2002).

Despite the similarities in recall initiation between younger and older adults, older adults tend to show less temporal contiguity across subsequent retrievals. The ability to use retrieved context to guide subsequent retrievals can be assessed using lag conditional response probabilities (Lag-CRPs). Lag-CRPs plot transition probabilities for successively retrieved items conditionalized on the distance (lag) between items during study. Lag-CRPs for unrelated lists are typically highest at adjacent lags (+1 and −1) and fall off smoothly as lags increase. These functions are asymmetrical in that probabilities at adjacent lags are higher in the forward (positive) than backward (negative) direction. This reflects the blending of contextual elements across subsequently studied items during encoding (e.g., Polyn, Norman, & Kahana, 2009). Older adults show lower probabilities on adjacent lags relative to younger adults, especially in the forward direction, which presumably reflects deficits in both encoding and retrieval of contextual information (Healy & Kahana, 2015).

Although PFR curves and Lag-CRPs derived from single-list free recall are useful for comparing age differences in recall initiation and retrieved context, they do not assess the contribution of controlled processing to the focus of retrieval. Alternatively, the dual-list free recall paradigm can leverage the operation of control processes by allowing retrieval conditions to be varied. When participants are instructed to recall from the first list, control processes are engaged to reinstate target context and avoid producing intrusions from the second list. Here, control processes work in opposition to responding on the basis of the similarity in temporal context between the second list and the test. Further, when participants are told to recall from the second list, they must use control processes to restrict the focus of their retrieval to the local context of the second list to avoid producing intrusions from the global context of the trial, which also includes the first list. Note that the demands on controlled processing are greater when the task is to recall from the first rather than second list because of the greater disparity between study and test contexts. The ability to recall responses from target lists and avoid intrusions from competing lists indicates successful use of control processes to reinstate context and focus retrieval appropriately. The extent to which this occurs should be captured by the recollection parameter estimate derived from the process dissociation procedure.

A more complete picture of age differences in the focus of retrieval can be gained by considering analyses of PFR curves together with differences between correct responses and intrusions in a dual-list paradigm. A useful feature of the dual-list paradigm for assessing the focus of retrieval is that PFR curves can be computed for the condition in which participants are instructed to recall from both lists. Younger adults are typically aware of contextual changes, which should be reflected in PFR curves that are sensitive to the distinct contexts created by the two study lists. In contrast, older adults' broader retrieval orientation might produce insensitivity to the two study contexts as revealed by recall being initiated at more distant positions across lists. The breadth of retrieval orientation is an important indicator of the amount of information that resides within the focus of search. A broader set is more likely to include competing information extraneous to the target list resulting in more intrusions. Together with an age-related deficit in recollection, a pattern of PFR curves showing more distant positions of recall initiation for older adults would provide converging evidence that control deficits impair context reinstatement and diminish precision in the focus of retrieval.

Executive Control and the Focus of Retrieval

Age differences in the breadth of retrieval orientation and their effects on recall performance can be informed by the relationship between individual differences in executive control and the focus of retrieval from secondary memory. Unsworth and Engle (2007) showed that higher order control abilities (i.e., working memory) predicted younger adults' ability to restrict the focus of retrieval to a target set of events in single-list free recall. Individuals with low working memory were more likely to recall intrusions from prior lists (i.e., proactive interference) than individuals with high working memory. Increased proactive interference for individuals with poor executive control was posited to result from poor elaboration of cues that produced noisier contextual representations and a broader focus of retrieval. Given that older adults generally show impaired executive control processes (for a review, see Braver & West, 2008), these findings suggest that noisier contextual representations should be established during recall initiation along with a broader retrieval focus for older than younger adults.

Overview of the Experiment

In the present experiment, we compared younger and older adults' ability to focus their retrieval to target sources using a dual-list free recall paradigm. Our paradigm was inspired by dual-list paradigms used in earlier studies (e.g., Epstein, 1972; Unsworth, Brewer, & Spillers, 2013). Table 1 provides a schematic of the trial types we included here. We included three dual-list conditions in which participants studied two lists of words. In one condition, we assessed retroactive interference effects by instructing participants to recall words from the first list only (List 1). In another condition, we assessed proactive interference effects by instructing participants to recall words from the second list only (List 2). In a third condition, we assessed memory for both lists by instructing participants to recall from the first and second lists (List Both). We also included two single-list trial types to serve as control conditions for the List 1 and

List 2 interference conditions. In the control condition for List 1 (List C1), the study list appeared in the first portion of the trial, but it was followed by a distractor task instead of second list. In the control condition for List 2 (List C2), a distractor task appeared in the first portion of the trial instead of the first list, and the study list appeared after.

Table 1. Overview of the Procedure

Trial type	Study phase		Recall
List C1	List 1	Distractor	List 1
List 1	List 1	List 2	List 1
List C2	Distractor	List 2	List 2
List 2	List 1	List 2	List 2
List Both	List 1	List 2	List 1 & List 2

Note. The above example represents a single block of trials in the experiment. List 1 and List 2 trial types represent retroactive and proactive interference situations, respectively.

We conducted a variety of analyses to characterize the effects of age-related control deficits on context reinstatement and the focus of retrieval. We were primarily interested in overall recall of correct responses and intrusions, estimates of recollection and automaticity derived from the process dissociation procedure, and PFR curves in the List Both condition. Based on the arguments presented above, we expected that older adults would recall fewer correct responses and more intrusions in the List 1 and List 2 conditions relative to younger adults. We expected these patterns to translate into a selective deficit in recollection for older adults and invariance in automatic influences across age groups, consistent with the bulk of the cognitive aging literature (for a review see, Koen & Yonelinas, 2014). Of critical importance, we expected PFR curves in the List Both condition to show qualitative differences for younger and older adults. Specifically, we expected younger adults to be sensitive to the substructure of the lists within a trial as revealed by primacy and recency effects in the second list. In contrast, we expected older adults to be insensitive to the substructure of the two lists in the form of primacy effects in the first list and recency effects in the second list. This finding would be consistent with theoretical frameworks positing that impairment in control processes results in inappropriately broad specification of retrieval cues (e.g., Burgess & Shallice, 1996; Jacoby, Shimizu, Velanova, & Rhodes, 2005).

We conducted additional analyses to provide a full characterization of age differences in context reinstatement throughout the recall period. Specifically, we computed PFR curves for the remaining conditions along with serial position curves, output profiles, target-list transition probabilities, and Lag-CRPs for all conditions. We expected PFR curves to replicate the age invariance in primacy effects on delayed tests and recency effects on immediate tests shown in earlier studies (e.g., Golomb et al., 2008; Kahana et al., 2002). We also expected serial position curves to replicate earlier studies showing greater primacy effects on delayed tests and greater recency effects on immediate tests (for a review, see Crowder, 1976). Importantly, we were particularly interested in whether serial position curves would show primacy effects on the second list of the List Both condition for both younger and older adults. If so, this would indicate that both groups were sensitive to the contextual break between lists during encoding.

Following Unsworth, Brewer, and Spillers (2013), we also computed output profiles for the dual-list conditions by plotting the probability of recalling responses from each list within a trial as a function of the output position during the recall period. Consistent with their results, we expected participants to initially recall more correct responses than intrusions with the probability of intrusions increasing at later positions (also see, Lohnas, Polyn, & Kahana, 2015). We expected convergence between correct recalls and intrusions to occur earlier in the recall period when greater demands were placed on control processes in List 1, especially for older adults. We assumed that this measure indexed a form of cognitive control that served to reinstate list-level contextual representations. We also computed target-list transition probabilities that assessed the likelihood of recalling subsequent responses from a target list, regardless of their original input position to provide a metric of the ability to reinstate list-level context throughout the recall period. Consistent with output profiles, we expected older adults to produce fewer successive correct recalls, especially in List 1, because of their impairment in the control processes necessary to sustain the reinstated context. Finally, we computed Lag-CRPs that we assumed reflected an item-level control process that was subordinate to the list-level control process. We expected more shallow functions for older adults reflecting a deficit in the ability to effectively reinstate item-level context to guide subsequent retrievals, consistent with earlier studies (e.g., Golomb et al., 2008; Kahana et al., 2002).

Method

Participants

Twenty-four younger adults (*M*age = 19.54 years, *SD* = 1.02, *Range* = 18–22) and 24 older adults (*M*age = 69.92 years, *SD* = 4.30, *Range* = 65–83) participated in the experiment. Younger adults were recruited from the undergraduate participant pool in the Department of Psychology at Washington University in St. Louis and were compensated with partial course credit or $10. Older adults were recruited from the St. Louis community through participant pools maintained by the School of Medicine and Department of Psychology at Washington University in St. Louis and were paid $15. Older adults reported more years of education (*M* = 15.92, *SD* = 2.39) than younger adults (*M* = 13.50, *SD* = 1.02), $t(46) = 4.54$, $p < .001$, and also had numerically higher vocabulary scores (*M* = 35.61, *SD* = 2.74) than younger adults (*M* = 34.71, *SD* = 1.73), $t(45) = 1.35$, $p = .18$, on the Shipley Institute of Living Scale (Shipley, 1986). One older adult did not complete the vocabulary test.

Design and Materials

A 5 (Trial Type: List C1 vs. List 1 vs. List C2 vs. List 2 vs. List Both) × 2 (Age: Younger vs. Older) mixed design was used. Trial type was manipulated within-subjects and age was a between-subjects variable. Materials were 320 concrete nouns from the MRC Psycholinguistic Database (Coltheart, 1981). Words were four to nine letters in length (*M* = 5.42, *SD* = 1.37), had concreteness ratings ranging from 502–670 (*M* = 578.83, *SD* = 30.53, *Scale* = 100–700), and Hyperspace Analog to Language log frequency counts that ranged from 6.94–12.60 (*M* = 9.63, *SD* = 1.11).

The experiment consisted of 20 study-test trials comprised of four blocks that each included one trial type from each of the five conditions (List C1, List 1, List C2, List 2, and List Both). Three conditions each included two 10-word study lists (List 1, List 2, and List Both), and two conditions (List C1 and List C2) each included one 10-word study list (8 lists × 10 words × 4 blocks = 320 words total). To counterbalance items across conditions, the 320 words were divided into 32 groups of 10 words that were matched on length, concreteness, and frequency. The groups were then clustered into eight larger ensembles each consisting of four groups. Each ensemble was assigned to one of the eight lists that comprised the trial type conditions. These ensembles were rotated through lists across experimental formats. The groups within the ensembles were assigned to specific trial blocks, and the groups remained in the same trial block across experimental formats. This resulted in words being presented equally often in each list, but not in each trial block, across eight experimental formats.

Procedure

Participants were tested individually. Each participant completed 20 study-test trials in which each trial type appeared once in each of four consecutive blocks (see Table 1). The presentation order of trial types within each block was randomized. At the beginning of the experiment, participants were provided with a brief description of the trial types. The List 1, List 2, and List Both conditions included two study lists. The List C1 condition included one study list followed by a distractor task, and the List C2 condition included a distractor task followed by one study list. Prior to all study lists, participants were told that they would see a list of words and that they should study the list for an upcoming test while reading the words aloud. Importantly, participants were *not* told which list they would be asked to recall prior to study. Ten words appeared for 1 s each followed by a 1-s interstimulus interval (20 s total) in random order. Prior to all distractor tasks, participants were told that they would see a three-digit number and that their task would be to count backward by threes aloud for 20 s to match the duration of the study lists. Following the second phase of each trial, participants completed a recall test. An instruction screen appeared telling participants which list to recall and that we were interested in the accuracy and time of their recall. Participants pressed a space bar to initiate the recall period once they finished reading the instructions. No other interpolated task occurred prior to the recall period. Participants were instructed to recall words aloud for 90 s in any order and to press the space bar when they recalled each word. A fixation point (+) appeared in the middle of the screen and changed colors when participants pressed the space bar to indicate that the response time had been recorded. An experimenter recorded the words recalled.

Results

Variations in degrees of freedom occurred when participants were excluded for failure to produce at least one observation per cell. Alpha was set to .05.

Overall Recall Performance

Table 2. Mean Responses Per Trial as a Function of Response Type, Trial Type, and Age Group

	Age group

Response/Trial type	Younger	Older
Correct recall		
List C1	5.51 (.83)	3.09 (.48)
List 1	4.23 (.78)	2.22 (.46)
List C2	6.24 (.55)	4.73 (.51)
List 2	5.46 (.60)	3.71 (.42)
List Both	9.54 (1.09)	5.67 (.68)
Intratrial intrusions		
List 1	0.70 (.27)	1.39 (.44)
List 2	1.00 (.47)	1.40 (.30)

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

Retroactive interference was greater than proactive interference across age groups, as shown by the difference between correct recall and intratrial intrusions being smaller in the List 1 (3.22 vs. 1.04) than List 2 (4.58 vs. 1.20) condition, $F(1, 46) = 24.23$, $p < .001$, $\eta p^2 = .35$. This is consistent with earlier studies showing that retroactive interference is more pronounced at short retention intervals, whereas proactive interference is more pronounced at longer retention intervals (Postman, Stark, & Fraser, 1968). Finally, older adults produced more prior-trial intrusions (.62 vs. .18), $F(1, 46) = 18.58$, $p < .001$, $\eta p^2 = .29$, extraexperiment intrusions (.43 vs. .17), $F(1, 46) = 8.79$, $p < .01$, $\eta p^2 = .16$, and repetitions of earlier output responses (.18 vs. .07), $F(1, 46) = 4.39$, $p = .04$, $\eta p^2 = .09$, than younger adults. Together, these results show that older adults were less able to discriminate target from nontarget responses.

Process Estimates: Recollection and Automaticity

We interpreted older adults' impaired ability to discriminate between target and nontarget responses as evidence for a recollection deficit. We verified this deficit by estimating the contributions of recollection and automaticity to recall using equations from a process dissociation procedure (Jacoby, 1991). To avoid complications with differences in the total number of responses that could have been produced, we only included correct recalls and intratrial intrusions. This approximates earlier studies in which each response type had an equal opportunity to be produced. The model assumes that correct recall occurred when a word was recollected (R) or when a word 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 an interfering list A(1 − R): Intratrial Intrusion = A(1 − R). The probability of recollection was estimated as the probability of correct recall minus the probability of an intratrial intrusion: R = Correct Recall − Intratrial Intrusion. Automaticity was then estimated using algebra: A = Intratrial Intrusion/(1 − R).

Our primary interest was whether older adults would show an overall deficit in recollection, rather than differences in process estimates across trial type conditions. Consequently, we derived estimates by collapsing correct recalls and intratrial intrusions across the List 1 and List 2 conditions, similar to the method used by Yonelinas (1994) in a recognition memory paradigm. The mean number of correct recalls and intratrial intrusions in Table 2 were converted to proportions and data from individual participants were submitted to the equations above. Six younger and three older adults were excluded for failure to produce any intratrial intrusions in both conditions. Figure 1 shows that estimates of recollection were higher for younger than older adults, whereas estimates of automaticity did not differ between age groups. This was confirmed by a significant Age × Process interaction, $F(1, 37) = 12.97$, $p = .001$, $\eta p^2 = .26$. Importantly, these results are the first to show a selective deficit in recollection for older adults in free recall.

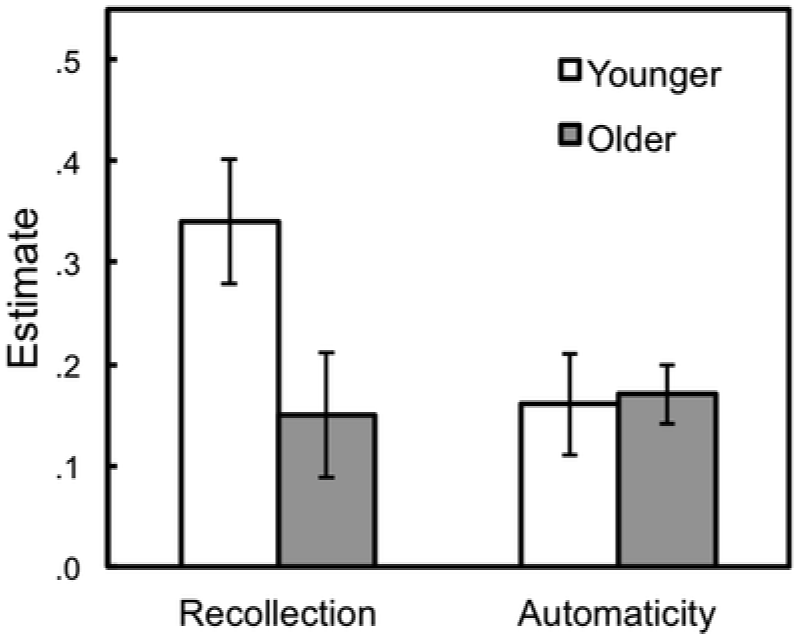

Figure 1. Process estimates for recollection and automaticity as a function of age. Error bars are 95% confidence intervals.

So far, we have established that older adults were less able to discriminate between correct responses and intrusions when recalling from a target list in a dual-list paradigm. This resulted from a recollection deficit that reflected impaired control processes necessary for reinstating the target list context. In the following analyses, we deconstruct free recall performance using the measures described in the Introduction to determine the consequences of age differences in context reinstatement for the organization of recall.

PFR Curves

We computed PFR curves (see Figure 2) to test for age differences in the manner of recall initiation. We conditionalized the probability of first recall on the input position of responses, and smoothed the data by averaging across three adjacent positions for all positions except the first and last. PFR curves in the List Both condition were of primary interest to our hypothesis about age differences in retrieval breadth. The top panels of Figure 2 show that older adults initiated retrieval from more distant locations across the study lists than younger adults. Older adults showed primacy effects in List 1 and recency effects in List 2, whereas younger adults showed both primacy and recency effects in List 2, $F(9, 414) = 2.73$, $p = .004$, $\eta p^2 = .06$. For both groups, recency effects were larger than primacy effects, consistent with PFR curves typically found on immediate tests. This pattern showed that older adults oriented the focus of their retrieval to the trial level, treating both lists as one longer list, whereas younger adults were sensitive to the substructure of the lists within the trial. We believe these patterns reflect older adults being less precise in their specification of retrieval cues resulting from impaired functioning of control processes.

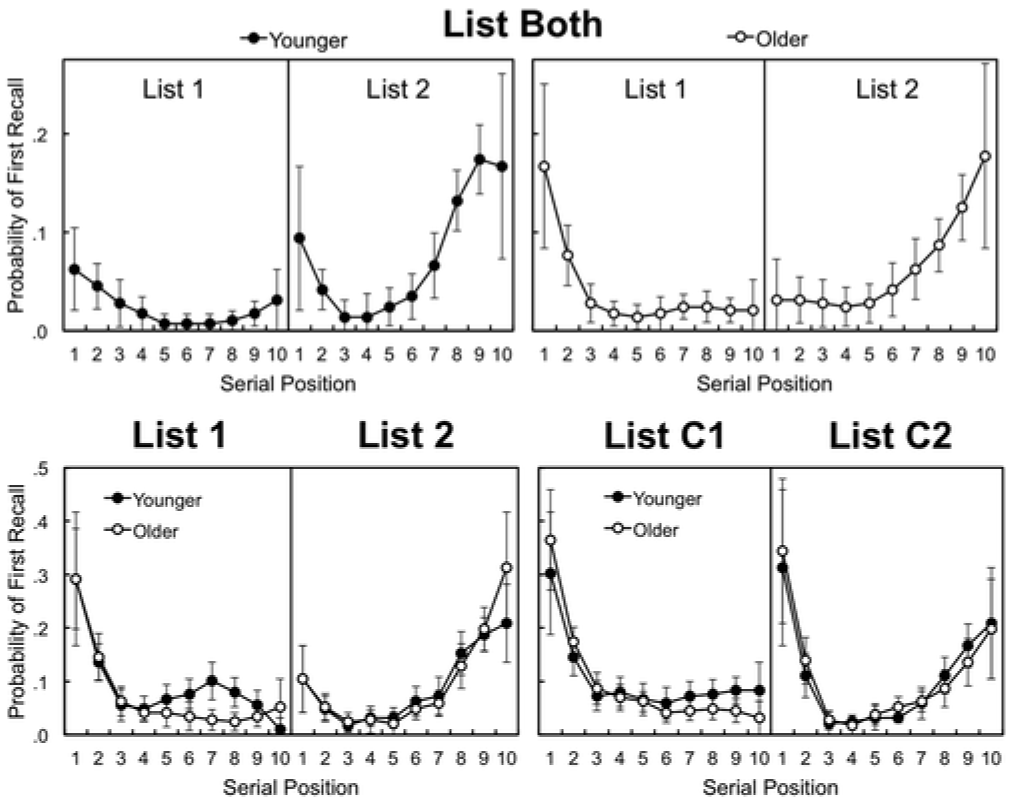

Figure 2. Probability of first recall curves for younger and older adults in the List Both condition (top panels), the List 1 and List 2 conditions (bottom left panels), and the List C1 and List C2 conditions (bottom right panels). Data were averaged across three adjacent positions within each list for all positions except the first and last. Error bars are 95% confidence intervals calculated using a bootstrapping procedure.

The bottom left panels of Figure 2 show that the manner of recall initiation did not differ between younger and older adults in the List 1 condition or the List 2 condition. In the List 1 condition, both groups initiated recall from the primacy portion of the list, $F(9, 414) = 24.30$, $p < .001$, $\eta p^2 = .35$. In the List 2 condition, both groups initiated recall primarily from the recency portion of the list, $F(9, 414) = 24.54$, $p < .001$, $\eta p^2 = .35$. These patterns were consistent with earlier findings on delayed and immediate tests, respectively (Golomb et al., 2008; Kahana et al., 2002).

The bottom right panels of Figure 2 show that recall initiation also did not differ between age groups in the List C1 condition or in the List C2 condition. In the List C1 condition, both groups initiated recall from the primacy portion of the list, $F(9, 414) = 30.20$, $p < .001$, $\eta p^2 = .40$, as in the List 1 condition. Surprisingly, in the List C2 condition, both groups initiated recall primarily from the primacy portion and to a lesser extent from the recency portion, *F*(9, 414) = 19.68, $p <$ .001, $\eta p^2 = .30$, inconsistent with the List 2 condition. This unexpected effect could reflect heightened attention to the primacy portion of the list resulting from the contextual break created by the prior distractor task, or possibly a difference in how participants controlled the distance that they looked back. We return to these possibilities when presenting serial position curves and in the Discussion section. Overall, the lack of Age × Position interactions in all the conditions above, *largest F*(9, 414) = 1.22, *p* = .28, $\eta p^2 = .03$, confirmed that both age groups initiated recall in a similar manner.

Serial Position Curves

Figure 3 displays serial position curves for younger and older adults, smoothed as for PFR curves. We examined serial position curves separately across trial types because we expected differences in study-test delays to influence the shapes of the curves (for a review, see Crowder, 1976).

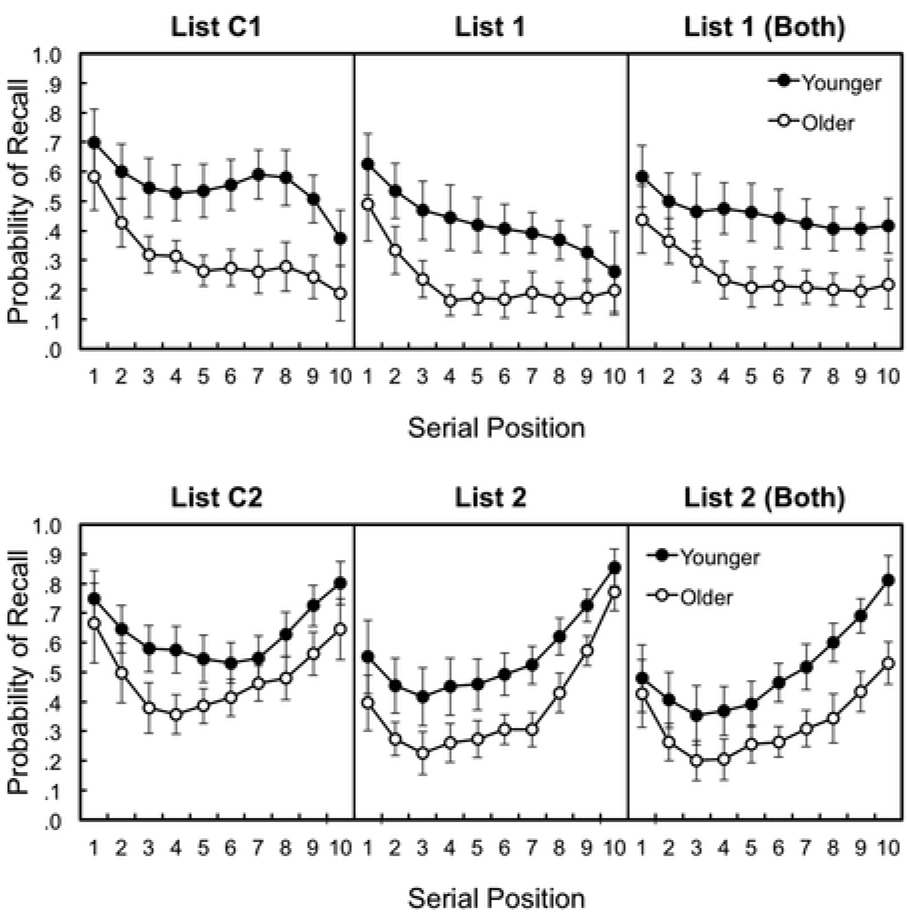

Figure 3. Serial position curves for younger and older adults in the List 1 conditions (top panel) and List 2 conditions (bottom panel). Data were averaged across three adjacent positions for all positions except the first and last. Error bars are 95% confidence intervals calculated using a bootstrapping procedure.

The serial position curves for List 2 in the List Both condition were of primary interest for our hypothesis that age differences in retrieval orientation revealed by PFR curves is an effect that goes beyond differences in encoding. The bottom right panel of Figure 3 shows that both younger and older adults were sensitive to the distinct contexts of the first and second lists during encoding in the List Both condition. Both primacy and recency effects were obtained in List 2 of the List Both condition with recency effects being larger than primacy effects. This pattern is consistent with typical serial position curves on immediate tests (Murdock, 1962). Older adults also showed larger primacy effects than younger adults, $F(9, 414) = 2.04$, $p = .03$, $\eta p^2 = .04$, confirming that both age groups were aware of the contextual break between List 1 and List 2 contexts during encoding. Taken together with the qualitative differences in PFR curves between younger and older adults in the List Both condition, these results support the notion that age-related deficits in control processes are related to poorer specification of retrieval cues.

Serial position curves for the List 2 condition in the bottom middle panel of Figure 3 were similar to those for List 2 of the List Both condition in showing larger recency than primacy effects for both age groups, $F(9, 414) = 47.96$, $p < .001$, $\eta p^2 = .51$. However, serial position curves in the List C2 condition in the bottom left panel differed from the previous two conditions in that primacy effects were similar in magnitude to recency effects for both age groups, $F(9, 414) = 15.22$, $p < .001$, $\eta p^2 = .25$. As noted for the PFR curves in the List C2 condition, the primacy effects may have resulted from the contextual break created by the preceding distractor task heightening attention to the primacy portion of the list, or by allowing participants to look further back when initiating retrieval.

The top panels of Figure 3 show primacy effects without recency effects for tests of List 1 items, which is consistent with earlier findings from delayed tests (Glanzer & Cunitz, 1966; Postman & Phillips, 1965). In the List C1 condition (left panel), an Age × Position interaction, $F(9, 414) = 2.03$, $p = .04$, $\eta p^2 = .04$, revealed primacy effects and negative recency effects across age groups with larger negative recency for younger adults because of a rise in the later-middle portion of the list. Similarly, in the List 1 condition (middle panel), a marginal Age × Position interaction, $F(9, 414) = 1.86$, $p = .06$, $\eta p^2 = .04$, showed greater primacy effects for older than younger adults and negative recency effects only for younger adults. Finally, List 1 of the List Both condition (right panel) showed primacy effects without recency effects that were equivalent for both groups, $F(9, 414) = 8.10$, $p < .001$, $\eta p^2 = .15$.

Output Profiles

In the next analysis, we assessed participants' ability to reinstate context at the list level across the recall period. Here, we examined output profiles that plot the probabilities of recalling an item from each list in the dual-list conditions as a function of output position. We assume that participants' ability to sustain context reinstatement from a particular list across subsequent recalls is indicated by the distance between the curves for each type of response. Figure 4 displays output profiles for younger and older adults in the List 1, List 2, and List Both conditions. Output profiles display the probabilities of correct recall and intratrial intrusions (for the List 1 and List 2 conditions) across 14 positions of the recall period. Later output positions ranging up to 24 were excluded because few responses (38 total across participants) were given.

We did not plot prior-list and extraexperimental intrusions because they obscured the comparisons between response types within a trial.

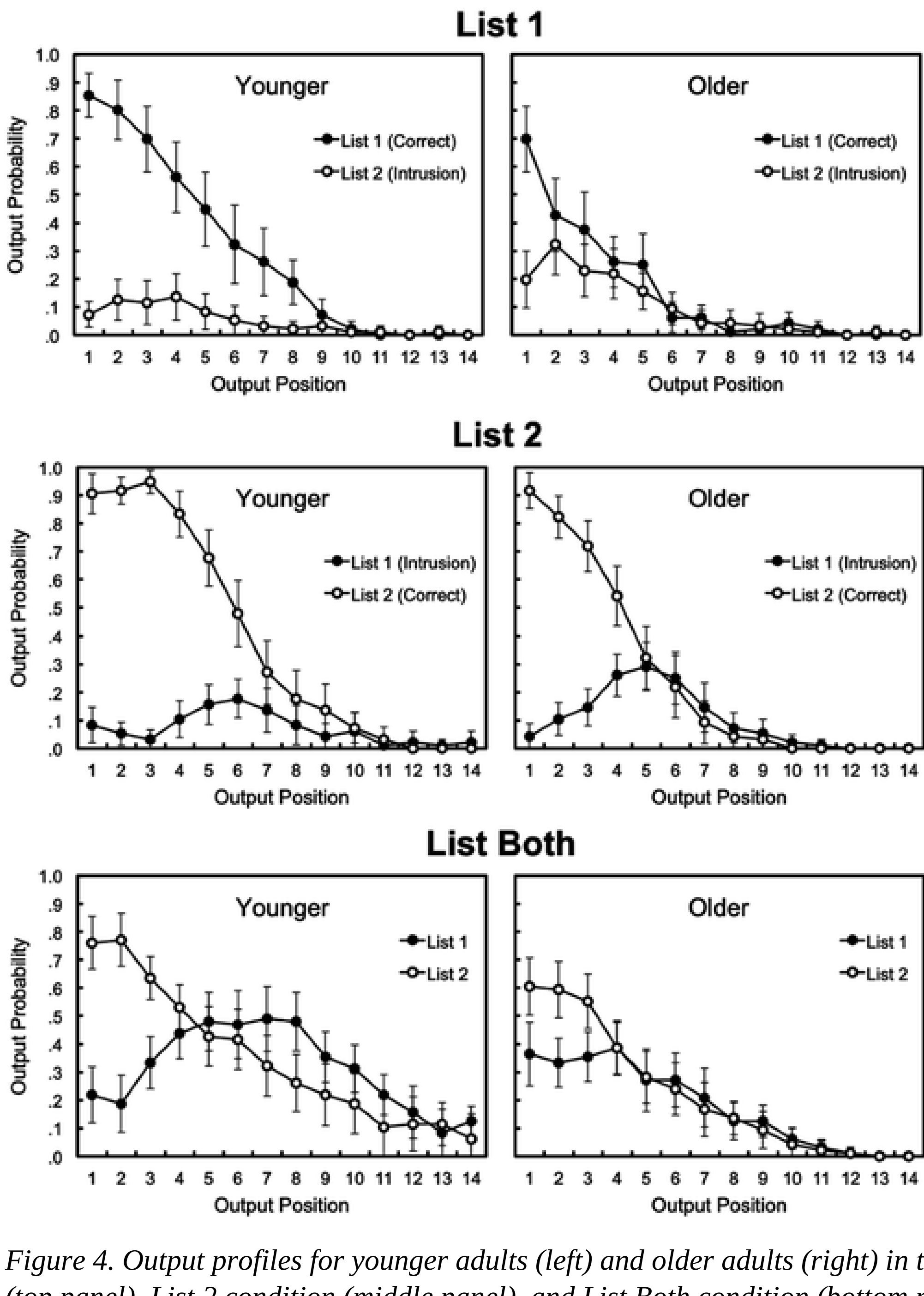

Figure 4. *Output profiles for younger adults (left) and older adults (right) in the List 1 condition (top panel), List 2 condition (middle panel), and List Both condition (bottom panel). Mean probabilities of producing a response from each list are plotted as a function of output position during the recall period. Intrusions refer to intratrial intrusions from the list opposite the target list. Error bars are 95% confidence intervals.*

We examined the List 1 condition (top panels) first because it placed the greatest demands on controlled processing by requiring context reinstatement from a more distant temporal context. Doing so required participants to avoid outputting responses based on the similarity between the study and test contexts, which was greater in List 2 than in List 1. We expected this condition to show the largest age differences in the ability to discriminate between correct recalls and intrusions across the recall period. Younger adults were more successful than older adults at consistently reinstating the target context throughout the recall period. Younger adults showed a higher overall probability of first recall from the target list than older adults, and older adults showed more rapid convergence between correct recalls and List 2 intrusions than younger adults, $F(13, 598) = 6.58$, $p < .001$, $\eta p^2 = .13$. These results show that younger adults were better able to use control processes to sustain reinstated context from the target list.

Next, we examined the List 2 condition (middle panels). We expected age difference in discriminability between response types across the recall period to be less pronounced relative to the List 1 condition because the demands on control processes to reinstate context were lower. Here, participants could recall items from the target list by relying on the similarity between study and test contexts to a greater extent. Older adults did show impairment in discriminating between correct recalls and intratrial intrusions relative to younger adults, $F(13, 598) = 6.67$, $p < .001$, $\eta p^2 = .13$. However, the age groups did not differ in their ability to recall from the target list on the first output position, indicating that the age difference in discrimination between sources was smaller and occurred later in the recall period than in the List 1 condition.

Finally, we examined the List Both condition (bottom panels) in which responses from both lists were targets. This condition showed participants' baseline tendency to output responses when neither list was prioritized for retrieval. Younger adults showed a tendency to prioritize recall from List 2 at the beginning of the recall period, and then shift to List 1 near the middle of recall, whereas older adults showed a similar tendency but to a lesser extent, $F(13, 598) = 2.16$, $p = .01$, $\eta p^2 = .05$. These results showed that older adults had a less sustained prioritization of recall from any particular list as compared to younger adults. Consistent with the conditions above, we believe that this tendency reflects an age-related deficit in cue specification subserved by list-level control processes.

Target-List Transition Probabilities

We computed target-list transition probabilities for the dual-list conditions (see Table 3) to provide a metric of list-level control. These show the probability of successive recalls of responses from a target list, regardless of input position. This metric captures the extent to which target-list context reinstatement is sustained across the recall period, as shown in output profiles. Consequently, we expected age differences in target-list transition probabilities to parallel differences in discrimination between correct recalls and intrusions shown in output profiles.

Table 3. Target-List Transition Probabilities as a Function of Trial Type and Age Group

	Trial type	
	Interference conditions	List both

Age group	List 1	List 2	List 1	List 2
Younger	.83 (.07)	.85 (.03)	.62 (.07)	.66 (.06)
Older	.53 (.09)	.69 (.06)	.42 (.09)	.57 (.05)

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

We submitted the transition probabilities from all conditions to a 2 (Age: Younger vs. Older) × 4 (Trial Type: List 1 [Interference] vs. List 2 [Interference] vs. List 1 [List Both] vs. List 2 [List Both]) mixed ANOVA. Two important differences were revealed by an overall Age × Trial Type interaction, $F(3, 138) = 5.95$, $p < .001$, $\eta p^2 = .11$. First, younger adults had greater overall transition probabilities than older adults, especially when recalling from List 1. Younger adults effectively engaged control processes to sustain reinstatement of target-list context across the recall period, whereas older adults were disproportionately impaired when higher levels of control were required to reinstate context from a further temporal distance. Second, the overall advantage for the interference conditions over the List Both condition was greater for younger than older adults. This result showed that when both groups were instructed to prioritize retrieval from a specific list, younger adults engaged control processes in service of reinstating target-list context more effectively than older adults.

Lag-CRPs

We conducted our final analyses to compare younger and older adults’ ability to use item-level control processes to reinstate context at retrieval. We assumed that the item-level transition probabilities assessed as Lag-CRPs indicated the extent to which participants could use control processes to reinstate and retrieve context for individual items, then guide their subsequent retrievals using the context provided by prior retrievals. We computed Lag-CRPs for every list across participants, collapsing across output position. Our general interest was whether Lag-CRPs would be more shallow for older than younger adults as shown before (Golomb et al., 2008; Kahana et al., 2002). Figure 5 shows that Lag-CRPs were more shallow for older than younger adults indicating less temporal contiguity in responding for older adults. A significant Direction × Lag × Age interaction, $F(4, 176) = 13.54$, $p< .001$, $\eta p^2 = .24$, indicated that probabilities were greater in the positive than negative direction, especially for adjacent lags, and this difference was greater for younger than older adults. Follow-up comparisons between age groups showed that probabilities were greater for younger than older adults at lags: +1 (.26 vs. .17), $t(46) = 3.89$, $p < .001$, −1 (.12 vs. .10), $t(46) = 2.49$, $p = .02$, and −2 (.08 vs. .05), $t(46) = 2.49$, $p = .02$. Together with results from output profiles and target-list transition probabilities, these results show that older adults had deficits in two forms of control processes that we believe resulted in the generation of underspecified retrieval cues that ultimately misguided the focus of their retrieval.

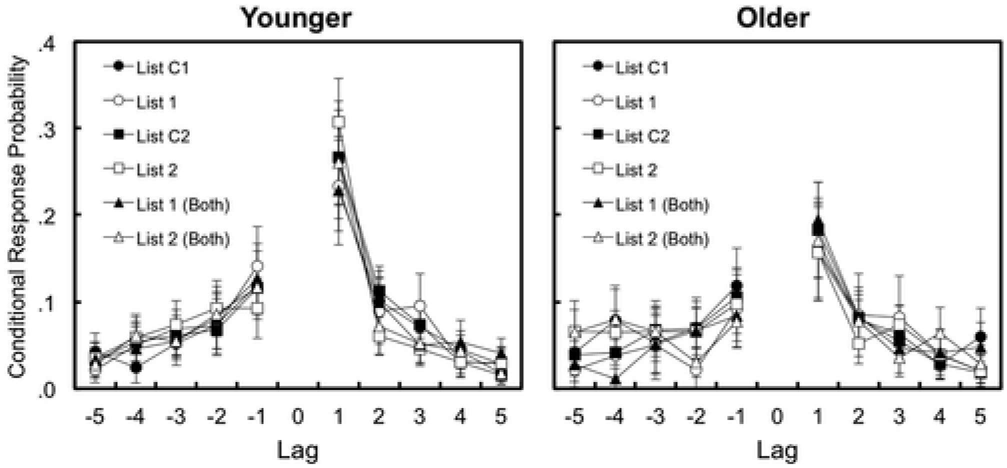

Figure 5. Conditional response probabilities as a function of lag and trial type for younger adults (left panel) and older adults (right panel). Error bars are 95% confidence intervals.

Discussion

In the present experiment, we used a dual-list free recall paradigm to demonstrate that age-related deficits in control processes impair the ability to reinstate context and focus retrieval to a target source. We found compelling evidence for these deficits using three primary measures. First, older adults were less likely to recall items from target lists and more likely to recall intrusions from nontarget lists as compared with younger adults. Second, a process dissociation procedure showed that control processes estimated by a recollection parameter were selectively impaired for older relative to younger adults. Third, older adults showed impoverished elaboration of retrieval cues when initiating recall, whereas younger adults were more precise in their specification of cues during recall initiation. Specifically, older adults' PFR curves in the List Both condition showed primacy effects in List 1 and recency effects in List 2, but younger adults' PFR curves in the List Both condition showed primacy and recency effects in List 2. This qualitative difference in retrieval orientation showed that older adults' recall initiation was insensitive to the substructure of the two lists within a trial, whereas younger adults' recall initiation was sensitive to the distinct contexts of the two lists.

We confirmed that age differences in the PFR curves in the List Both condition reflected differences in controlled retrieval processes and were not simply due to encoding differences by comparing them with serial position curves. Both younger and older adults' serial position curves in the List Both condition showed primacy effects in List 2, indicating that both groups encoded the context break that separated the lists. We also provided preliminary evidence showing that older adults were impaired on multiple levels of cognitive control. We assumed that output profiles and their corresponding target-list transition probabilities indexed a form of cognitive control that served to reinstate list-level contextual features. Subordinate to this level of control, we assumed that Lag-CRPs indexed a form of cognitive control that served to reinstate item-level contextual features. Older adults' impairment on both levels of control was shown by their decreased ability to consistently reinstate target-list context throughout the recall period and by their decreased temporal contiguity in responses as compared to younger adults. We discuss these results along with their theoretical implications in more detail below.

The measures of retrieval dynamics that we obtained by deconstructing recall performance largely replicated other findings reported in the literature. We found no age differences in PFR curves for immediate and delayed tests, and we also found that Lag-CRPs were more shallow for older than younger adults (Golomb et al., 2008; Kahana et al., 2002). Serial position curves did not reveal larger primacy effects for younger than older adults as shown earlier (Craik, 1968), but they did show that older adults were especially impaired in the middle of the list, consistent with other findings (Capitani, Della Sala, Logie, & Spinnler, 1992; Kahana et al., 2002). We did not replicate the statistically reliable finding of Lag-CRPs being more shallow on delayed than immediate tests (Howard & Kahana, 1999) for either age group, but we did observe a trend in that direction. Overall, the consistency between the present results and earlier studies shows that a dual-list free recall paradigm is a valid tool for examining how changes in aspects of retrieval processes contribute to age-related deficits in episodic memory.

An important finding from our dual-list paradigm was that PFR curves in the List Both condition were qualitatively different for younger and older adults. At first glance, one might conclude that this difference merely reflects age difference in encoding processes. Indeed, research has shown that contextual changes occur more slowly for older than younger adults (Balota, Duchek, & Paullin, 1989), and this could potentially cause older adults to blend contextual features across breaks between study lists. Evidence for this notion has been shown in studies examining memory for word pairs and perception of naturalistic events. Campbell, Trelle, and Hasher (2014) used an associative recognition task to show that older adults were more likely to bind context across subsequently studied word pairs than younger adults. Zacks, Speer, Vettel, and Jacoby (2006) showed that older adults were less likely to perceive event boundaries in ongoing naturalistic activities than younger adults. Despite these findings, encoding differences between younger and older adults cannot fully account for the differences in the PFR curves we observed in the List Both condition. As described above, serial position curves from the List Both condition showed primacy effects in List 2 that were actually greater for older than younger adults. Together with the fact that participants were required to press a key to begin the second list, these results show that both groups were aware of the distinct context between lists during encoding, but older adults were largely insensitive to the contextual break when initiating retrieval. More generally, these findings have theoretical implications for the long running debate regarding whether age differences in episodic memory reflect an encoding deficit, or whether retrieval deficits exist beyond encoding (for a review, see Zacks, Hasher, & Li, 2000). Clearly, older adults showed impairment in their controlled initiation of retrieval that went beyond an encoding deficit in the present experiment.

An unexpected result obtained with PFR curves was that in the control condition for List 2 (List C2), PFR curves revealed massive primacy effects and less pronounced recency effects. This pattern contrasts with that typically shown for immediate tests in which recency effects dominate primacy effects (Howard & Kahana, 1999; Kahana et al., 2002). One account of these findings is that the breakpoint between trials created by the distractor task that preceded the study list may have heightened participants' attention to the primacy portion of the list, which is consistent with predictions of event segmentation theory (Zacks, Speer, Swallow, Braver, & Reynolds, 2007). Additional evidence for this account was shown by disproportionately larger primacy in effects in serial position curves for the List C2 condition relative to the other List 2 conditions. In addition to heightened attention, it is possible that the dramatic context break between trials signaled participants to the decreased probability of producing prior-list intrusions. Consequently, participants may have broadened their focus of retrieval to the earliest portion of the study list that was presumably encoded more effectively as a result of the context break. Evidence for this possibility has been shown in studies demonstrating that individuals can use cognitive control to guide the breadth of their retrievals (Jacoby, 1974; Jacoby & Wahlheim, 2013; Jacoby, Wahlheim, & Kelley, 2015; Wahlheim, Maddox, & Jacoby, 2014). Given the intimate link between attention and memory, both enhanced encoding and controlled retrieval likely contributed to these effects.

As described in the beginning of the article, a desirable feature of the dual-list paradigm is that it can be used to assess the role of cognitive control in age differences in interference effects. Contemporary interference theories posit that cognitive control is required to focus retrieval to target information and prevent competing information from coming to mind (e.g., Anderson & Spellman, 1995; Hasher, Zacks, & May, 1999; Zacks & Hasher, 1994). Given that older adults have well-documented deficits in executive control (for a review see, Braver & West, 2008), their greater susceptibility to interference could reflect impaired control mechanisms used to sustain active maintenance of list context representations (Braver et al., 2001; Polyn et al., 2009). In this vein, older adults have been shown to experience longer periods of goal neglect in tasks requiring executive control relative to younger adults (West, 2001). Further, these periods of neglect are exacerbated in situations that place high demands on control processes (West, Murphy, Armilio, Craik, & Stuss, 2002). We posit that our current finding showing that younger adults did not differ in their target-list transition probabilities between the List 1 and List 2 conditions, whereas older adults show a disproportionately greater deficit in the List 1 than List 2 condition reflects a situation where older adults' ability to sustain contextual representations was dramatically impaired because of the high demands placed on control processes.

In this vein, the dual-list paradigm also provides insight into age differences in the operation of multiple levels of control during retrieval in an episodic memory task. The distinction between levels of control we make here corresponds to the distinction between sustained and transient control processes posited to play critical roles in constraining the focus of retrieval (Velanova, Jacoby, Wheeler, McAvoy, Petersen, & Buckner, 2003). We posit that output profiles and their corresponding target-list transition probabilities index the sustained reinstatement of list-level contextual representations that are superordinate to transient item-level contextual representations. We also posit that Lag-CRPs index the ability for individuals to reinstate item-level contextual representations that preserve the temporal coherence of events subordinate to the list context. To make this distinction concrete, consider a commonplace example of describing an event from a prior day to a friend in a conversation. List-level control would be akin to the mechanism required to focus and sustain retrieval to the particular day of the event, or even the target event itself within the day. In contrast, item-level control would be akin to the mechanism necessary to coherently describe details of the event in their original order. In the present experiment, we showed that older adults were impaired in both forms of control, with the impairment being disproportionately greater in the List 1 condition only for list-level control. Similar distinctions between levels of control have been made in the visual attention domain, most notably in the Stroop task (Bugg, 2012; Jacoby, Lindsay, & Hessels, 2003). Future theoretical development stands to benefit from determining how similar concepts can be leveraged to understand age differences in cognitively controlled retrieval processes.

A further distinction that has not been considered by theories of age differences in episodic memory is that between recollection and automaticity in free recall. As described above, recollection is a consciously controlled process that constrains retrieval to target contexts, whereas automaticity brings information to mind devoid of contextual details. This distinction has largely been ignored in free recall because this task has often been assumed to be a pure measure of recollection (Aggleton & Brown, 1999; Quamme, Yonelinas, Widaman, Kroll, & Suavé, 2004; Yonelinas et al., 2002). However, several studies using the remember-know procedure (Tulving, 1985) have shown that recollection and automaticity may also contribute to free recall (Hamilton & Rajaram, 2003; McDermott, 2006; Mickes, Seale-Carlisle, & Wixted, 2013). The present experiment is the first to use the process dissociation procedure to estimate the contributions of recollection and automaticity in a free-recall task in which retrieval was cued by lists. Our findings extend earlier studies that used the process dissociation procedure in recognition (Jacoby, 1999) and cued recall (Hay & Jacoby, 1999; Jacoby et al., 2001), by showing an age-related recollection deficit in free recall. The role of recollection in age differences in free recall is of theoretical interest because of the similarity between the cue elaboration involved in recollection and the self-initiated retrieval process described by computational models of free recall (e.g., Healy & Kahana, 2015).

The role of automaticity in age differences in free recall is also of theoretical interest because it is unclear how automatic influences contribute to recall performance. One possibility is that items that come to mind automatically are devoid of contextual information (Mickes et al., 2013). These responses may be output when participants misattribute the heightened accessibility of the items to their being from the target list (McCabe, Roediger, & Karpicke, 2011). This misattribution could in part be responsible for older adults' tendency to report more intrusions. This would suggest that older adults also have a deficit in postretrieval monitoring (Hashtroudi, Johnson, & Chrosniak, 1989; Healy & Kahana, 2015). However, no models of age differences in free recall have considered the relationship between automatic retrievals and postretrieval monitoring processes as described here. Further research comparing age differences in objective estimates from the process dissociation procedure and subjective estimates from the remember–know procedure could inform this relationship.

In conclusion, the present findings show that older adults' episodic memory deficit in part reflects deficient control processes that impair context reinstatement and the focus of retrieval. Older adults' impairment in controlled retrieval was shown by a selective recollection deficit and by a broader retrieval orientation relative to younger adults. Both list- and item-level cognitive control mechanisms were implicated as underlying the ability to prevent the deleterious effects of proactive and retroactive interference. Further research should examine how a postretrieval editing mechanism applied to automatic retrievals contributes to age differences in free recall. More generally, the present experiment highlights the importance of seeking convergence between behavioral methods and computational models to assess how various aspects of retrieval contribute to age-related deficits in episodic memory.

Footnotes

1 A concern raised by one reviewer was that older adults' higher level of education might have obscured the actual magnitude of age differences in recall performance. Specifically, age differences in correct recall would be underestimated if education and recall were positively associated. Against this possibility, younger adults reported fewer years of education and demonstrated higher recall than older adults. Further, within each age group, education and recall were not positively associated. Correlations between overall correct recall and years of education were conducted for each age group. Younger adults showed a marginal *negative* correlation, $r(22) = -.38$, $p = .06$, and older adults showed *no* correlation, $r(22) = .04$, $p = .87$. Thus, it is unlikely that older adults' higher education produced an underestimation of their recall deficit.

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