Research Report

SECOND THOUGHTS VERSUS SECOND LOOKS: An Age-Related Deficit in Reflectively Refreshing Just-Activated Information

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Abstract—*Age-related deficits in memory are greater as encoding and retrieval tasks require more reflective (self-generated or executive) processing. One problem in developing more specific models of age-related changes in cognition is that the tasks studied tend to be complex and vary in the combinations of component cognitive processes they recruit. Here we report an age-related deficit in one of the most elementary, but critical, components of reflection: refreshing a just-activated representation. Impairment in such a process potentially has a wide-ranging impact on all higher-order cognition.*

Perceptual stimuli create activation that decays without attention (e.g., Sperling, 1960). Decay refers to a reduction in a temporary state change; the fact that activation occurred may nevertheless produce long-term consequences, for example, making it easier to activate the same item again (e.g., Forbach, Stanners, & Hochhaus, 1974; Hebb, 1961). Attention is a summary term encompassing various reflective mental operations (i.e., component processes) that maintain, manipulate (e.g., organize, compare), revive, and evaluate information (e.g., Johnson, 1992). Within the Multiple-Entry, Modular memory framework (MEM; Johnson, 1992, 1997), these operations include working memory (e.g., Baddeley, 1992) processes that are also the encoding processes (e.g., Tulving, 1962) that determine long-term memory. For example, *refreshing* is an operation in MEM that prolongs activation of just-activated representations. Other operations include *rehearsing* (a purposeful recycling of information, often for the purpose of recalling it soon), *reactivating* (the relatively automatic revival of no-longer-active representations), and *retrieving* (reviving no-longer-active representations through the strategic self-generation of cues). Thus, the refresh operation is one of the simplest reflective (i.e., self-generated or executive) processes in the MEM framework.

A fundamental question about the cognitive consequences of aging is whether aging compromises all reflective processes, or affects them more selectively (Craik & Jennings, 1992; Salthouse, 1991). For example, age-related deficits in memory are greater as encoding and retrieval tasks require more self-generated or executive processing (Craik, Morris, & Gick, 1990; Light, 1991). Such findings suggest that age-related deficits might occur only when reflective processes become sufficiently complex, such as when multiple component processes must be combined. Alternatively, aging might compromise even the most elementary reflective operations. We investigated this question in the present study by examining whether there are age-related deficits in refreshing a just-activated representation.

In Phase 1, participants read as quickly as possible a list of unrelated words presented sequentially on a computer. Critical words were presented once (*single-presentation* condition), immediately repeated (*repeat* condition), or followed by a dot (•), which signaled participants to think of the just-previous word and say it again (*refresh* condition). Interspersed in the presentation list were perceptual identification trials in which words appeared in degraded form, making them difficult to read. Half of the degraded words were the critical words from previous trials and half were new. Phase 2 was a surprise recognition test in which the three types of critical words were randomly mixed with new words that had not been encountered in Phase 1, and participants indicated whether each word was old or new.

We were primarily interested in three comparisons of single-presentation, repeated, and refreshed words: (a) response times to say the words, (b) response times to identify them on perceptual identification trials (an indirect memory task), and (c) long-term recognition (a direct memory test). On the basis of previous findings (e.g., Howard & Wiggs, 1993; La Voie & Light, 1994), we expected older adults to show intact facilitation from prior perception of a word on perceptual identification trials (priming). On the basis of reports that age-related deficits are less likely the simpler the task (e.g., Craik & Jennings, 1992), it seemed that refreshing might be intact as well, as manifested both in the time to refresh and in any potential positive impact of refreshing on long-term retention. On the other hand, a recent neuroimaging study of young adults found greater activity in dorsolateral prefrontal cortex during refresh trials than during repeat or single-presentation trials (Raye, Johnson, Mitchell, Reeder, & Greene, in press). Given evidence of age-related neuropathology in frontal cortex (Raz, 2000), older adults might show a deficit even in such a simple reflective process as refreshing.

METHOD

Participants

Participants were 27 young (M = 19 years, range: 18–21) and 27 older (M = 74 years, range: 67–84) adults. (An additional 8 young and 6 older participants were excluded because their voices did not trigger the voice key reliably.) Young adults were Princeton undergraduates participating as part of a course requirement or for payment. Older adults (M education = 16.12 years, SD = 2.16; self-rated to be in general good health) were from Princeton and surrounding communities and were paid to participate.

Materials and Procedure

Phase 1 included 45 words in each condition (single-presentation, repeated, and refresh). These 135 critical items were also presented, along with 135 other items, in degraded form (missing a random 50% of their pixels) for perceptual identification. All items were intermixed with the constraint that critical items were never presented in a de-

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graded form before appearing in nondegraded form, and the average number of items between the nondegraded and degraded versions of words was equated across the three conditions. Thus, critical items were presented once before the degraded version in the single-presentation condition, presented twice before the degraded version in the repeat condition, and presented once and refreshed once before the degraded version in the refresh condition. The intervals between nondegraded and degraded versions comprised other critical words and filler words (an additional 270 words). During Phase 1, all items were displayed on a computer screen in letters 0.75 in. high presented against a background of high-frequency noise. Items were presented at a 2.5-s rate (2 s on, 0.5-s interitem interval), and response times were collected via voice key. Responses were recorded on audiotape; trials in which the voice key was triggered by erroneous responses, coughs, or other extraneous sounds were discarded. The mean proportions of responses omitted for young and old adults were, respectively, .08 and .04 on first presentation of any item, .09 and .07 on the critical (single-presentation, repeated, refresh) trials, and .08 and .09 on the perceptual identification trials.

In Phase 2 (which began approximately 5 min after Phase 1 ended), the 135 critical items were randomly mixed with 135 completely new items, and participants responded via two buttons labeled "old" and "new" to indicate whether or not each word was from Phase 1. Test items were displayed at a 2.0-s rate (1.5 s on, 0.5-s interitem interval) in nondegraded form.

For each age group, critical words were rotated through the conditions and were old or new for perceptual identification and for recognition equally often. In addition, the mean number of syllables (1.66) and mean frequency (42; Kuçera & Francis, 1967) were matched across conditions.

RESULTS

For each dependent variable of interest, a Condition (within subjects) × Age (between subjects) analysis of variance (ANOVA) was followed by planned comparisons of conditions ($\alpha = .05$ unless otherwise noted). In all ANOVAs, there was a main effect of age: Older adults responded more slowly in the first phase and less accurately in the second (recognition) phase of the experiment than young adults. The analyses reported here, however, focus on the condition and Age × Condition effects that were of central interest. There were three main sets of findings:

Older Adults Took Disproportionately Longer to Refresh a Word

Figure 1 shows the time to say words in Phase 1. There was an Age × Condition interaction, $F(2, 104) = 19.39$, $MSE = 783.36$. Participants read a word faster if they had read it before, $F(1, 52) = 293.13$, $MSE = 293.52$, and this repetition priming effect was of similar magnitude for both age groups, as indicated by the absence of an Age × Condition (repeat vs. single-presentation) interaction, $F < 1$. In contrast, older adults were slower than young adults to say the previously presented word on refresh trials relative to their corresponding reaction times on the single-presentation trials, as indicated by an Age × Condition interaction, $F(1, 52) = 17.82$, $MSE = 1{,}138.20$. A second analysis of these data controlled for differences between age groups in baseline (single-presentation) response times. Each participant's mean response times in the repeat and refresh conditions were expressed as a

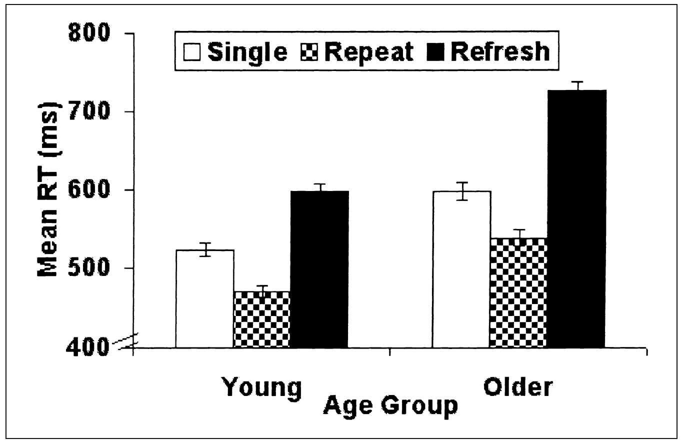

Fig. 1. Mean response time (RT; in milliseconds) to say words aloud on single-presentation, repeat, and refresh trials. Bars indicate standard error of the mean.

proportion of his or her mean response time in the single-presentation condition. The Age × Condition (repeat vs. refresh) interaction was significant in this analysis, $F(1, 52) = 10.33$, $MSE = 0.004$; although young and older adults did not differ on repeat trials ($M = .90$ for each), older adults were slower than young adults on refresh trials (1.22 and 1.14, respectively), $t(52) = -2.96$.

The fact that older adults were disproportionately slower than young adults on refresh but not repeat trials suggests that their performance was not simply disrupted when the same item had to be processed again. That is, participants said the same word aloud again in both the repeat and the refresh conditions, but only in the refresh condition were they required to "mentally go back" to the item. Thus, the nature of the processing—reflection or perception—mattered.

A control experiment assessed whether older adults' performance was disrupted by the need to switch from reading words to another task. Eight new participants from each age group were asked to respond "dot" whenever a dot appeared. The mean reaction times for older adults were 591, 547, and 598 ms for the single-presentation, repeat, and dot conditions, respectively, compared with 548, 496, and 543 ms for the young adults. Older adults again showed a significant benefit on the repeat relative to single-presentation trials, $t(7) = 8.50$, as did young adults, $t(7) = 5.51$. Furthermore, there was no evidence of a task-switching disruption in response times of the older adults on the dot trials relative to the single-presentation trials, $ts(7) = -0.60$ and 0.34, for old and young adults, respectively.

Older Adults Showed Intact Priming From Prior Perception

Figure 2 shows time to identify the degraded words. In an Age × Condition (new, single-presentation, repeat, refresh) ANOVA, there was a main effect of condition, $F(3, 156) = 114.85$, $MSE = 174.69$, but no Age × Condition interaction, $F < 1$. Young and older adults showed similar facilitation of perceptual identification from a single prior presentation (items in the single-presentation condition) relative to no prior presentation (new items; 29 and 35 ms, respectively) and from two prior presentations (items in the repeat condition) relative to a single prior presentation (14 and 13 ms, respectively). Neither young

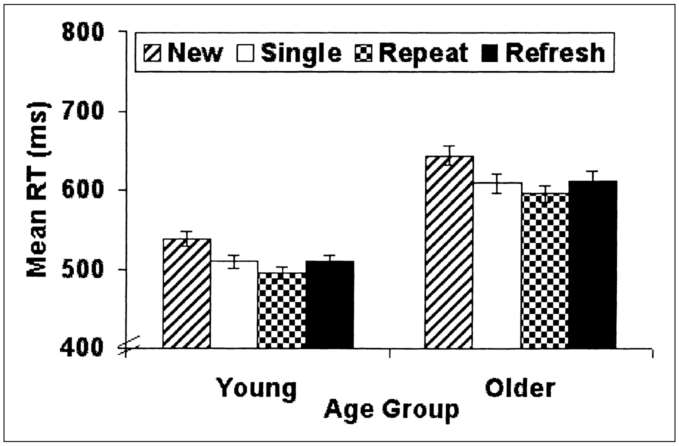

Fig. 2. Mean response time (RT; in milliseconds) to identify degraded old (single-presentation, repeat, and refresh) and new words. Bars indicate standard error of the mean.

nor older adults showed any additional benefit of refreshing an item on later perceptual identification relative to having seen an item once (−1 and −3 ms, respectively). These results are consistent with others demonstrating facilitation of perceptual identification from prior perception but not from prior generation (Jacoby, 1983).

Older Adults Showed Less Benefit From Refreshing an Item on a Later Recognition Test

Figure 3 shows corrected recognition scores (hits minus false positives) from Phase 2. In an Age × Condition ANOVA, there was a main effect of condition, $F(2, 104) = 9.56$, $MSE = 0.006$, but the Age × Condition interaction was not significant. Nevertheless, when planned comparisons were conducted separately for each group, young adults' old/new recognition was better for words that had been repeated than for words presented once, $t(26) = 3.14$, and better for words that had been refreshed than for words that had been repeated, $t(26) = 2.07$, whereas for older adults neither of these comparisons was significant (ts = 0.84 and 0.80, respectively). Furthermore, across both age groups, the time to respond on refresh trials in Phase 1 (with time to respond on repeat trials partialed out) was negatively correlated with the corrected recognition scores on refresh items ($r = -.34$, $p = .01$). That is, participants who refreshed quickly had higher recognition scores later on these items.

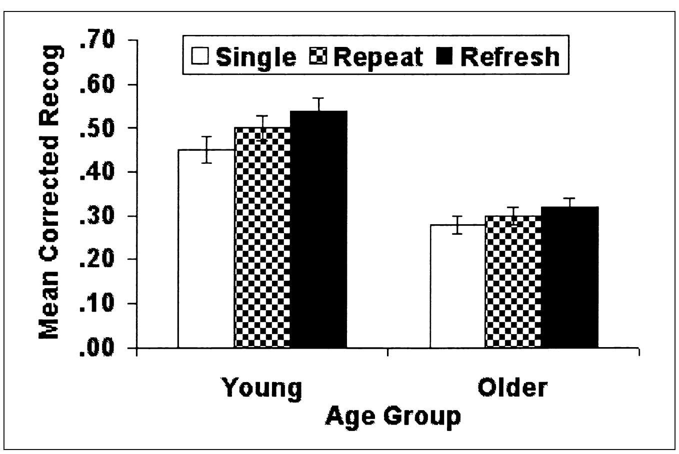

Fig. 3. Mean corrected recognition (Recog) scores (proportion correct minus proportion of false positives) on single-presentation, repeat, and refresh trials. Bars indicate standard error of the mean.

DISCUSSION

Older adults showed intact perceptual processing: The repetition priming effect and the facilitation of perceptual identification from both a single prior exposure and a second presentation were similar for older and young adults. These results replicate and extend previous findings that older adults show relatively preserved memorial consequences of perceptual processes on indirect memory tests (e.g., Fleischman & Gabrieli, 1998; Howard & Wiggs, 1993; La Voie & Light, 1994).

In contrast, there was an age-related deficit in the simple reflective operation of thinking of a just-presented item (refreshing). Older adults were slower to refresh words, and derived less long-term benefit on recognition memory from the refresh operation. With more complex tasks (e.g., Allen, Mahler, & Estes, 1969; Landauer & Bjork, 1978; but see Hogan & Kintsch, 1971), young adults show benefits for long-term memory of being tested on items relative to seeing them again. Similar studies with older adults have produced conflicting results, and interpreting them is complicated by differences in success rates of young and older adults prior to the final test (see Koutstaal, Schacter, Johnson, Angell, & Gross, 1998, for discussion). In the present study, we attempted to isolate a single reflective process. Evidence that older adults saw the critical items was their preserved perceptual identification; evidence that they thought of the critical items was their correct responses when the dot signaled them to think of and say the just-presented item (refresh trials). In short, under conditions designed to equate age groups on the occurrence of the process in question, there was an age-related deficit. It should be noted that we cannot yet say whether this age-related effect arises from a problem in engaging the refresh process or in carrying it out.

We recently used functional magnetic resonance imaging (fMRI) to investigate the refresh process in young adults (Raye et al., in press). In a refresh paradigm similar to the one reported here, an area of left dorsolateral prefrontal cortex (BA 9) was more active during refresh trials than during single-presentation or repeat trials. Activity was greater in this region for words that were subsequently recognized than for words that were not, providing converging evidence that the cognitive operation of refreshing involves brain regions whose activation has an impact on long-term memory performance. An age-related refresh deficit is consistent with evidence that neuropathology in frontal regions increases with age (Raz, 2000). In addition, recent neuroimaging findings suggest there are age-related differences in frontal activations in both working memory (Mitchell, Johnson, Raye, & D'Esposito, 2000) and long-term memory (Cabeza et al., 1997; Schacter, Savage, Alpert, Rauch, & Alpert, 1996), but the tasks used to date have been relatively complex and have not isolated specific component processes. Neuroimaging studies using procedures similar to the one in the present study may provide evidence about the brain regions implicated in the age-related refresh deficit reported here.

The cognitive consequences of a refresh deficit could be profound. For example, we speculate that one function of the refresh operation could be to facilitate binding together features of complex experience by prolonging the duration of their joint activation (e.g., Chalfonte & Johnson, 1996; Mitchell, Johnson, Raye, & D'Esposito, 2000; Prabhakaran, Narayanan, Zhao, & Gabrieli, 2000) or by maintaining a feature's activation until more slowly encoded features are represented. Even given adequate encoding, a refresh deficit could still compromise episodic memory; during remembering, if individuals cannot refresh the information a cue activates, they might be at a disadvantage in evaluating its source (e.g., Johnson, Hashtroudi, & Lindsay, 1993; Mitchell, Johnson, Raye, Mather, & D'Esposito, 2000, Experiment 2).

We further speculate that a refresh deficit may play a role in other age-related cognitive phenomena as well. Activated but irrelevant representations persist more for older than young adults, suggesting that older adults may have a deficit in inhibitory processes that suppress the activation of task-irrelevant information (Hasher, Zacks, & May, 1999). Such an inhibitory deficit could be exaggerated by a refresh deficit. If task-appropriate representations are not selectively refreshed, their activation levels may not exceed those of potential competitors. In other words, the failure to inhibit irrelevant information may in part reflect a failure to refresh the activation of relevant information. That is, refreshing appropriate representations presumably helps make them a source of inhibition rather than the object of inhibition from other representations.

Thinking depends on the ability to keep goals and subgoals active. It also depends on the ability to combine items of information that occur successively. A key mechanism by which this is accomplished is sustaining activation of information across brief time intervals so that it can be used as related information is activated, or so that some features can be bound to other incoming features, depending on task demands. A common complaint of older adults is that thoughts are fleeting—they cannot revive information that was active only a second ago (e.g., they have a thought as someone is speaking, but cannot "pick up" the thought by the end of the speaker's sentence; or they lose their own thought as they speak; or they cannot remember why they came into the kitchen). A possible account of these cognitive difficulties ("senior moments") is that activation dissipates more quickly as people age. However, preserved perceptual priming among older adults suggests that this is not the case, as does the persistence of irrelevant information (Hasher et al., 1999). Here we offer an alternative explanation: There is an age-related deficit in a specific reflective process, refresh, which operates during ongoing cognition to prolong or increase activation of information that is potentially relevant to task goals (Johnson, 1992). Such a deficit could affect performance on many tasks, and its influence would be compounded with increasing task complexity insofar as more complex tasks may require refreshing a greater number of activated, agenda-relevant representations.

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