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Article *in* Psychology and Aging · April 2008

DOI: 10.1037/0882-7974.23.1.93 · Source: PubMed

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Psychology and Aging
2008, Vol. 23, No. 1, 93–103

0882-7974/08/$12.00 DOI: 10.1037/0882-7974.23.1.93

Age-Related Deficits in Associative Memory: The Influence of Impaired Strategic Retrieval

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In 2 experiments, the authors investigated whether impaired strategic retrieval processes contribute to the age-related deficit in associative memory. To do so, they compared older and younger adults on measures of associative memory that place high demands on retrieval processes (associative identification and recall-to-reject) to measures that place low demands on such processes (associative reinstatement and recall-to-accept). Results showed that older adults were severely impaired on associative identification and recall-to-reject measures; relatively intact on recall-to-accept measures, unless recollection was prominent; and intact on associative reinstatement measures. Together, these findings suggest that impairment in strategic retrieval accounts for older adults' deficits in memory for associative information and that this deficit, above and beyond poor binding of items, leads to and amplifies an impairment in overall recollection.

Keywords: associative memory, recollection, familiarity, recall-to-reject, aging

Aging has a greater detrimental effect on contextually rich or associative memory relative to context-free or item memory. For instance, older adults have more difficulty explicitly discriminating between novel and studied combinations of items that they have previously experienced on an associative recognition task, which we term *associative identification*, than between studied and unstudied individual items on an item recognition task (Light, Patterson, Chung, & Healy, 2004; Naveh-Benjamin, 2000; Naveh-Benjamin, Hussain, Guez, & Bar-On, 2003). Two hypotheses have been advanced to account for this age-related deficit in associative memory: impairments in binding individual pieces of information during the encoding phase (Chalfonte & Johnson, 1996; Naveh-Benjamin, 2000; Naveh-Benjamin et al., 2003) and impairments in recollection at retrieval (Light, Prull, La Voie, & Healy, 2000; Yonelinas, 2002), which may result from poor binding at encoding, impaired strategic processes at retrieval, or both. The purpose of the present study was to assess the contribution of these types of impairment to age-related deficits in associative memory.

Binding Hypothesis and Retrieval Failure

According to the binding hypothesis, older adults are impaired primarily at binding items with one another at encoding, but not at encoding the items themselves (Chalfonte & Johnson, 1996; Naveh-Benjamin, 2000; Naveh-Benjamin et al., 2003). Consequently, associative identification suffers, whereas item memory is less affected.

Associative identification differs from item memory not only with respect to binding, but also in that it requires greater instantiation of a recall-like process at retrieval, which involves elaboration of retrieval cues, memory search, and postretrieval monitoring. This process is needed especially to overcome the sense of familiarity associated with studied items that are rearranged in a novel way and to reject them in favor of intact items that were paired together at encoding. Because associative identification requires this strategic recall-like process, which may be reduced in older adults, possible evidence of preserved ability to form and retain associative information may be left undetected.

Indeed, when demands on strategic retrieval abilities are minimized, older adults' memory for associations, and thus binding, is relatively preserved. For instance, older adults' hit rates to intact pairs on associative identification tasks are often equivalent to those of younger adults, even when controlled for differences in response bias (Castel & Craik, 2003; Healy, Light, & Chung, 2005). This implies that older adults can recognize associative information if the environment reinstates it for them, but have difficulty recovering this information on their own when rearranged pairs are presented.

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This work was supported by the Natural Sciences and Engineering Council of Canada Grant CFC 205055 Fund 454119 and the Canadian Institutes of Health Research Grant MT6694. We thank Alice Kim and Katherine Duncan for their assistance conducting the experiments; Marilyne Ziegler for her programming skills; and Patrick S. R. Davidson, Asaf Gilboa, and Deborah Talmi for helpful comments. We also thank Andrew Yonelinas for the algorithm used in Experiment 1.

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In addition, comparable gains on declarative tests of item memory have been observed in younger and older adults when test items are presented in their studied context rather than when they are presented alone or in a new context (Naveh-Benjamin & Craik, 1995; but see Bayen, Phelps, & Spaniol, 2000; Castel & Craik, 2003). We refer to tests of this type as tests of *associative reinstatement*. Unlike tests of associative identification, tests of associative reinstatement do not require participants to distinguish consciously between intact pairs and other items, but instead simply require participants to indicate whether the items were studied with no reference to how they were paired. Thus, strategic processes are not overtly required. Though the performance gain is small (9%–16% in young adults), the effect sizes are large (Cohn & Moscovitch, 2007; Humphreys, 1976; Tulving & Thomson, 1971).

Together, the reviewed findings indicate that the age-related deficit in associative memory may be caused as much by faulty retrieval mechanisms as by faulty binding at encoding. This observation is captured by the associative deficit hypothesis (Naveh-Benjamin, 2000; Naveh-Benjamin et al., 2003), which emphasizes the deficit in binding and acknowledges the effect of poor retrieval processes, though the latter has been investigated to a much lesser extent (but see Naveh-Benjamin, Brav, & Levy, 2007).

Recollection Hypothesis and Retrieval Failure

From a dual-process model of recognition memory perspective (e.g., Atkinson & Juola, 1974; Jacoby, 1991; Mandler, 1980; Yonelinas, 1997), older adults have impaired recollection but relatively intact familiarity at retrieval (see Light et al., 2000; Yonelinas, 2002, for reviews). *Recollection* is a process characterized by the conscious retrieval of associative information regarding an event's occurrence and is typically thought of as effortful and recall-like, whereas *familiarity* refers to a general, rapid, and relatively automatic feeling of oldness.

Item memory relies on both familiarity and recollection, whereas associative identification relies more on recollection because explicit retrieval of relational information is needed. On the latter tasks, recollection takes two forms: recall-to-accept and recall-to-reject. Recall-to-accept supplements familiarity to endorse intact pairs that reinstate items and their associations. Recall-to-reject opposes familiarity to reject pairs composed of studied items reshuffled in a novel way (rearranged pairs). Hence, a general recollection deficit should affect both forms and result in a *mirror effect*, that is, reduced hit rates to intact pairs and increased false alarm rates to rearranged pairs (Kelley & Wixted, 2001; Yonelinas, 2002). However, older adults' deficits are more evident, and sometimes solely present, on recall-to-reject relative to recall-to-accept measures (Castel & Craik, 2003; Healy et al., 2005). Thus, older adults may use recollection successfully when good memory cues are provided (e.g., intact pairs) but fail when the task requires more recall-like processes (as in the case of the rearranged pairs). In other words, it is the effortful access to recollection that seems problematic, rather than recollection in general.

Overview of Experiments

In the present study, our goal was to verify whether strategic retrieval failure can account, at least in part, for the age-related deficit in associative memory. In Experiment 1, we derived several measures of associative memory using a pair and an associative recognition task to determine the contribution of deficits in binding, in general recollection, and in retrieval processes to age-related deficits in associative memory. We compared the performance of older and younger adults on associative memory measures that place high demands on self-initiated retrieval processes (associative identification and recall-to-reject) and measures that place lower demands on such processes (associative reinstatement and recall-to-accept). Impaired binding should lead to deficits on all measures, whereas impaired retrieval processes should affect associative identification and recall-to-reject more (Cohn & Moscovitch, 2007). Similarly, a general recollection deficit should affect recall-to-reject and recall-to-accept, whereas a deficit in strategic retrieval processes should impair recall-to-reject more.

In Experiment 2, we further addressed the recollection hypothesis by promoting recollective processes even for intact pairs on an associative identification recognition task. To do so, we asked participants to recall information that was associated with the test probe at the time of study to assist them in making the appropriate decision (accept intact pairs and reject rearranged pairs). We hoped to evaluate whether the quality of the recollected information was comparable across age groups, especially with regard to the recall-to-accept ability, which was relatively intact on quantitative measures (hit rates) in previous studies (Castel & Craik, 2003; Healy et al., 2005). A greater or sole deficit in recall-to-reject compared to recall-to-accept would support the importance of retrieval processes, whereas equal reductions would suggest a general recollection deficit.

Experiment 1

In Experiment 1, our aim was to investigate whether older adults' associative memory deficits extend to all associative memory measures that require binding, are limited to measures based on recollection, or are limited to measures reliant on strategic retrieval processes. To do so, we compared younger and older adults using a word-pair recognition paradigm composed of a single study phase followed by a pair and an associative recognition task. The associative recognition task required participants to discriminate intact pairs from rearranged, half-old, and new pairs and assessed associative identification, recall-to-reject, and recall-to-accept abilities. The pair recognition task required participants to distinguish pairs of old words, whether intact or rearranged, from pairs containing at least one new word. Because both intact and rearranged pairs reinstate item information, but only the intact pairs reinstate the studied association, performance should be enhanced in terms of accuracy and speed on the intact pairs if associative information is retrieved. Associative reinstatement effects measure associative memory in a context that is not dependent on recall-like processes because retrieval of associative information is not overtly required. In addition, our tasks yielded measures of item memory and estimates of familiarity and recollection (based on a recall-to-reject ability) using a process dissociation procedure (Yonelinas, Regehr, & Jacoby, 1995).

We predicted, based on our previous findings using manipulations that interfered with relational binding at encoding or with retrieval processes in young adults (Cohn & Moscovitch, 2007),

Table 1
Mean (SD) Proportion of "Old" Responses for Each Item Type and Tasks for Experiment 1

	Pair recognition task				Associative recognition task			
Group	New	Half-old	Rearranged	Intact	New	Half-old	Rearranged	Intact
Younger	.10 (.11)	.28 (.13)	.70 (.13)	.82 (.10)	.02 (.03)	.05 (.01)	.14 (.11)	.72 (.14)
Older	.17 (.13)	.36 (.20)	.66 (.16)	.76 (.15)	.08 (.11)	.17 (.03)	.32 (.18)	.71 (.13)

that impaired binding in older adults should result in reduced performance across all associative memory measures. By contrast, impaired strategic retrieval processes with intact binding should result in reduced associative identification and recall-to-reject, but intact associative reinstatement and recall-to-accept. As for a general recollection deficit, it should result in poor associative identification ability characterized by a mirror effect, that is, high false alarm rates to rearranged pairs (poor recall-to-reject) and low hit rates to intact pairs (poor recall-to-accept) on the associative recognition task. Alternatively, recollection may be disproportionately or solely reduced when retrieval strategies are most crucial, namely when recall-to-reject is used.

Method

Participants. Twenty-four younger[1] and 24 older adults, all of whom were native English speakers, participated and received a course credit or $10 CAN/hour compensation. The younger adults (13 women and 11 men) were undergraduate students from the University of Toronto. Their ages ranged from 18 to 28 years ($M =$ 20.6). The older adults (16 women and 8 men) were high-functioning, healthy individuals drawn from the University of Toronto Adult Pool. Their ages ranged from 62 to 82 ($M = 70.7$), and their scores on the Mini-Mental State Examination (MMSE; Folstein, Folstein, & McHugh, 1975) ranged from 26 to 30 ($M =$ 28.8). Younger adults' mean score on the Vocabulary subtest of the Shipley Institute of Living Scale (Shipley, 1986) was lower ($M = 31.8$) than that of older adults ($M = 36.3$), $t(46) = 4.00$, $p <$ .001, $d = 1.20$. Mean number of years of formal education did not differ between the younger ($M = 14.0$) and older adults ($M =$ 14.5), $t < 1$. One younger participant and one older adult participant were replaced because of technical problems and failure to comply with the task instructions, respectively.

Material. A total of 384 word pairs were created by combining one 7-letter noun (first word) with a semantically unrelated 6-letter noun (second word). Pairs were arranged into lists of 12 pairs, in which each word had two possible pairings (A–B and C–D, as well as A–D and C–B). Lists were of equal Kucera-Francis frequency ($M =$ 36.3, range = 1–211) and were assigned, in a counterbalanced manner, to one of four types of items (new pairs, half-old pairs, rearranged pairs, or intact pairs), to one of two test types (pair or associative recognition), and to one of two study test blocks.

For each of the two blocks, 126 word pairs were presented at study, of which three were buffer pairs placed at the beginning and three were buffer pairs placed at the end of the study list. Both the pair and associative recognition tasks were composed of 96 randomly presented test items, including 24 *new pairs*, which were composed of nonstudied words (X–X); 24 *half-old pairs*, which were created by combining 24 words from 12 studied pairs with nonstudied words (A–X or X–D); 24 *rearranged pairs*, which were new pairings composed of studied words (A–D or C–B); and 24 *intact pairs*, which consisted of the studied pairs (A–B or C–D). The 7-letter and 6-letter words were presented on the left and right sides, respectively. Two practice phases were included for each test, one using descriptions of all possible test items and one using buffer items.

Procedure. Participants were tested individually. During the study phases, participants were instructed to remember the words and their pairing for a later test and were required to generate a sentence, aloud, that contained the two words, was meaningful, and maintained both the form (i.e., singular) and order of the words as they appeared on the screen. Each pair was presented for 5 s and was followed by a fixation cross that remained on the screen until the sentence was completed or after a reasonable delay was allowed but no sentence was initiated. On average, study phases were 13.4 and 15.4 min long for younger and older participants, respectively, $t(46) = 2.20$, $p < .05$, $d = 0.67$. Young and older adults were successful at creating sentences for 91% and 93% of the word pairs, respectively ($t < 1$).

Each study phase was followed by two different old–new recognition tests in a counterbalanced order. Both speed and accuracy were stressed. In the associative recognition task, participants were asked to identify studied pairs. That is, they had to respond "old" only to intact pairs. In the pair recognition task, participants were asked to identify pairs containing two studied words, regardless of their pairing. That is, they had to respond "old" to rearranged and intact pairs. Participants keyed in their "old" and "new" responses with their left and right index fingers using the *v* and *m* keys. The response-key mapping was counterbalanced across participants. Both the younger and older adults performed two study test blocks with a 3- to 5-min break in between, during which background information was collected. The Vocabulary subtest of the Shipley Institute of Living Scale and the MMSE (older adults only) were administered at the end of the testing session.

Results

In the current study, the older adults' performance did not differ as a function of task order or study test block. Therefore, data from the first and second block were collapsed. Proportions of "old" responses to each type of item in both recognition tasks for each age group are presented in Table 1. From these data, we derived

[1] Data from younger and older adults were collected concurrently, with the data from younger adults being compared with those of (a) older adults in this study and (b) other younger adults in another study dealing exclusively with young adults (Cohn & Moscovitch, 2007).

Table 2
Mean (SD) of Median Reaction Times per Pair Type and Recognition Task for Experiment 1

	Pair recognition task (ms)				Associative recognition task (ms)			
Group	New	Half-old	Rearranged	Intact	New	Half-old	Rearranged	Intact
Young	1,713 (436)	1,921 (524)	1,711 (409)	1,428 (262)	1,318 (205)	1,458 (269)	1,758 (431)	1,552 (362)
Older	2,112 (612)	2,366 (641)	2,184 (663)	1,870 (400)	1,741 (460)	2,119 (686)	2,408 (833)	2,060 (617)

measures of item memory, associative identification, familiarity, recollection, accuracy-based associative reinstatement, as well as performance on rearranged pairs (recall-to-reject) and intact pairs (recall-to-accept) from the associative recognition task. We also report the response time per item type and recognition task in Table 2. The speed-based associative reinstatement measure was derived from the response times on the pair recognition task. We tested group differences separately on these measures using *t* tests. We used 2 (young, old) × 2 (memory measures) repeated measures analyses of variance to test disproportionate age-related decline between item memory and associative identification, familiarity and recollection,[2] and recall-to-reject and recall-to-accept.

Item memory and associative identification. We derived d' scores indexing item memory and associative identification from the hit rate to rearranged pairs and false alarm rate to new pairs in the pair recognition task, and from the hit rates to intact pairs and false alarm rate to rearranged pairs in the associative recognition task, respectively. False alarm rates of 0 were adjusted to 0.02. As shown in Figure 1, item memory and associative identification were both reduced in the older, relative to the younger, group: item memory, $t(46) = 3.15$, $p < .01$, $d = 0.91$; associative identification, $t(46) = 3.83$, $p < .001$, $d = 1.14$. Unexpectedly, there was no age-related disproportionate decline across these measures: interaction, $F(1, 46) = 1.52$, $p = .22$, partial $\eta^2 = .03$.

Familiarity and recollection estimates. Another way to test for this uneven decline was to compare estimates of familiarity and recollection computed using a process dissociation procedure (Yonelinas et al., 1995).[3] The two processes were isolated mathematically from the hit rates to rearranged pairs in the pair recognition task (which result from recollection and familiarity working together) and the false alarm rates to the rearranged pairs in the associative recognition task (which result from familiarity in the absence of recollection). As shown in Figure 2, younger adults' recollection estimate was significantly greater than that of older adults, $t(46) = 3.71$, $p < .001$, $d = 1.07$; but the familiarity estimate was not different between the two age groups and, if anything, showed a reverse pattern ($t < 1$). Our data confirmed a disproportionate effect of aging on familiarity and recollection: interaction, $F(1, 46) = 11.56$, $p < .001$, partial $\eta^2 = .20$.

Associative reinstatement measures. We reasoned that if associative information is bound and stored in memory, reinstatement of this information at test may enhance performance on what is essentially an item memory task (i.e., greater hit rates and faster response times to intact pairs relative to rearranged pairs). We computed two measures of associative reinstatement: accuracy-based and speed-based associative reinstatement. The accuracy-based associative reinstatement measure was obtained by subtracting the d' score derived from the proportion of "old" responses to rearranged and new pairs from the d' score derived from the proportion of "old" responses to intact and new pairs in the pair recognition task (see Bayen et al., 2000, for a similar procedure). The speed-based associative reinstatement measure was derived by subtracting the median response time to correctly endorsed rearranged pairs from the median response time of correctly endorsed intact pairs on the pair recognition task. As shown in Figure 3, there were no age-related differences on the reinstatement measures (accuracy-based: $t < 1$, $d = 0.17$; speed-based: $t < 1$, $d = 0.10$), which suggests that associations were bound, stored, and

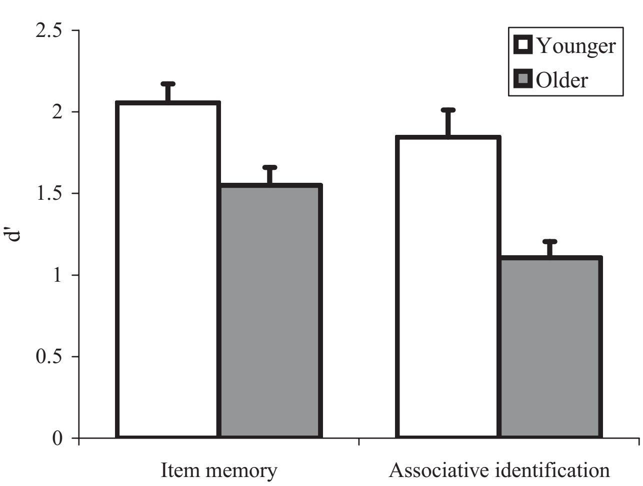

Figure 1. Mean item memory and associative identification in younger and older adults with standard error in Experiment 1.

[2] We used standardized *z* scores in this analysis to correct for the scale difference used for each process and, thus, eliminated the main effect of processes.

[3] In Yonelinas et al.'s (1995) process dissociation procedure, recollection is described as a threshold process and familiarity follows a signal detection process. We used a spreadsheet-based algorithm that computed recollection and familiarity estimates. The computations we used controlled for response bias across tasks and participants by incorporating the false alarm rates to new pairs from each task. Recollection is the difference between hits to rearranged pairs on the pair recognition task (familiarity + recollection) and the false alarm rate to rearranged pairs on the associative recognition task (familiarity only). Familiarity is expressed using a discriminability score (d')-derived F with $\Phi(d' / 2 - c)$, where Φ represents the probability of an item's familiarity exceeding the criterion (c).

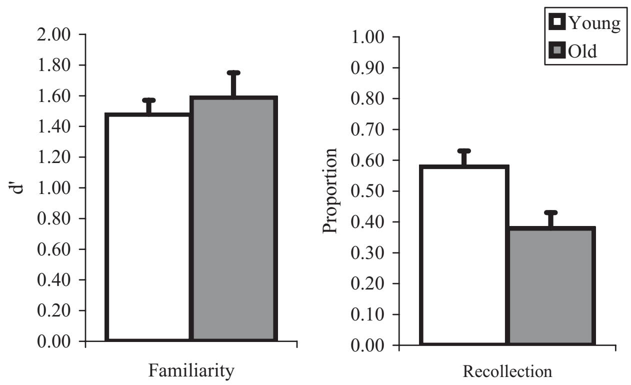

Figure 2. Mean familiarity and recollection estimates in younger and older adults with standard error in Experiment 1.

accessed at retrieval by both age groups to enhance their performance on an item memory task.

Performance on the rearranged and intact pairs in the associative recognition task. To further test the strategic retrieval failure and the general recollection deficit hypotheses, we contrasted older and younger adults' hit rate to intact pairs (recall-to-accept) and false alarm rate to rearranged pairs (recall-to-reject) in the associative recognition task. As noted earlier, strategic processes are needed especially to oppose a sense of familiarity to reject rearranged pairs; they are less needed when the environment reinstates the associative information (intact pairs). As shown in Table 1, older adults' false alarm rate to rearranged pairs was significantly greater than that of younger adults, $t(46) = 4.26$, $p < .001$, $d = 1.27$, whereas there was no age-related difference in hit rates to intact pairs, $t < 1$, $d = 0.10$. These data suggested that older adults' difficulties in discriminating between studied and novel associations on an associative recognition task were due primarily to their poor recall-to-reject ability and less so to their recall-to-accept ability: interaction, $F(1, 46) = 7.23$, $p = .01$, partial $\eta^2 = .14$.

Discussion

Together, our findings suggest that older adults (a) were able to bind and store associative information at least to a sufficient level to retrieve it, and perhaps recollect it, when the test conditions were minimally demanding in terms of self-initiated retrieval processes (i.e., associative reinstatement and recall-to-accept); but (b) were impaired in retrieving this information in situations that were highly demanding in terms of self-initiated retrieval processes (associative identification and recall-to-reject). Thus, strategic retrieval processes appear to play an important role in accounting for the age-related deficit in associative memory and challenge, to some extent, the binding (Chalfonte & Johnson, 1996; Naveh-Benjamin, 2000; Naveh-Benjamin et al., 2003) and general recollection deficit hypotheses (Light et al., 2000; Yonelinas, 2002). The implications of these findings are addressed further in the General Discussion section.

A surprising, secondary finding from this experiment was the equivalent age-related declines in item memory and associative identification, which contrasts with previous studies (Castel & Craik, 2003; Naveh-Benjamin, 2000) and with our results showing intact familiarity and impaired recollection. There are two ways to explain this finding: Older adults' associative memory was enhanced or their item memory was reduced in the current study, or both. We are not convinced by the enhanced associative memory explanation, given that the magnitude of the associative identification deficit observed in the current experiment is comparable to that found in the literature and because the use of a similar encoding strategy did not eliminate the disproportionate deficit in associative memory in the study by Naveh-Benjamin et al. (2007).

We find the reduced item memory explanation more convincing. Such reduction is not related to older adults' potential confusion between the two recognition tasks given the absence of an order effect, but is instead related to the inclusion of two words rather than one in the test probe. In keeping with this explanation, Mitchell, Johnson, Raye, Mather, and D'Esposito (2000) showed that older adults perform more poorly on an item working memory task when such test probes are used. This difficulty may be compounded by the inclusion of half-old items that contain one familiar studied item. As a result, the increase in uncertainty in this task compared with single-item task may promote the use of recollection even for single items and lead to an age-related deficit decline in all conditions.

Experiment 2

Data from Experiment 1 imply that recall-to-reject, one variant of recollection highly reliant on strategic retrieval processes (e.g., cue specification and cue elaboration), is impaired in older adults. Although recall-to-accept appears better preserved, it remains unclear whether it is truly intact in older adults (i.e., that the quality of the recollected information is comparable across age groups). Our data also imply that recall-to-reject (i.e., the use of recollected information as disqualifying evidence) is the strategy used by participants to reject rearranged pairs and, thus, is the locus of older adults' deficit. The evidence, however, is only speculative and other strategies, such as the distinctiveness heuristic, may also be used by younger participants and be reduced in older ones (Gallo, Bell, Beier, & Schacter, 2006; but see Dodson & Schacter, 2002). This strategy is based on the failure to recollect contrasted to participants' recollective expectations (e.g., these words were

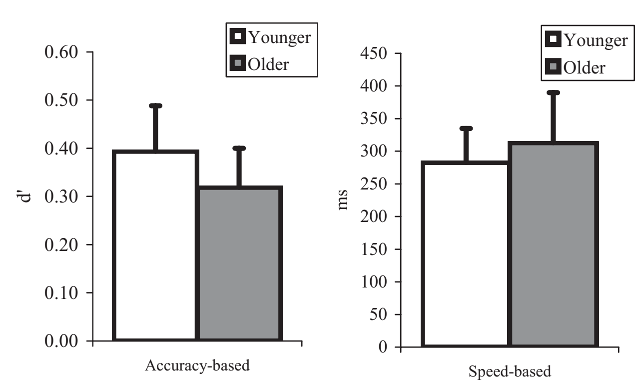

Figure 3. Mean accuracy-based (d') and speed-based (ms) associative reinstatement measures in younger and older adults with standard error in Experiment 1.

not studied together because if they were I would remember the sentence that I had created).

We addressed these issues in Experiment 2 using an associative recognition task. In it, participants were required to recall the studied associate of either one of the two words in each rearranged pair (accurate recall-to-reject) and to recall the sentence generated during study for each of the intact pairs (accurate recall-to-accept). By their doing so, we can determine the kind of information available to older and younger adults when making both types of decisions. Relative to Experiment 1, requiring such recall will likely benefit younger adults' associative identification score, but it is unclear whether it will also enhance older adults' scores. Indeed, Healy et al. (2005) showed no gain in older adults' performance when instructed to use a recall-to-reject strategy, whereas Naveh-Benjamin et al. (2007) found greater gains in older participants relative to younger ones when instructed to use a recall-to-accept strategy. Based on the results of Experiment 1, we predicted that older adults would be worse than younger adults in reporting the original studied word in the recall-to-reject condition, but we could not predict with certainty how they would perform on the recall-to-accept phase. We speculated that asking older and younger adults to provide information about the original encoding condition would invoke more recollection processes in the recall-to-accept phase than had existed in Experiment 1.

Method

Participants. Twenty-four younger and 24 older adults, all of whom were native English speakers, participated and received a course credit or $10 CAN/hour compensation. The younger adults (20 women and 4 men) were undergraduate students from the University of Toronto. Their ages ranged from 18 to 22 years (M = 19.1). The older adults (18 women and 6 men) were high functioning, healthy individuals drawn from the University of Toronto Adult Pool. Their ages ranged from 65 to 80 (M = 72.6). Their scores on the MMSE (Folstein et al., 1975) ranged from 26 to 30 (M = 29.1). Younger adults' mean score on the Vocabulary subtest of the Shipley Institute of Living Scale (Shipley, 1986) was lower (M = 29.9) than that of older adults (M = 35.6), $t(46) = 7.11$, $p < .001$, $d = 2.04$. Mean number of years of formal education did not differ between the younger (M = 13.5) and older adults (M = 13.8), $t < 1$. One older participant was replaced because of technical problems.

Material. A total of 120 word pairs were created by combining one 7-letter noun (first word) with a semantically unrelated 6-letter noun (second word). Pairs were arranged into lists of 12 pairs, in which each word had two possible pairings (A–B and C–D, as well as A–D and C–B). Lists were equated in terms of Kucera-Francis frequency (M = 37.0, range = 1–183). Each list was assigned to one of three types of items (new pairs, rearranged pairs, or intact pairs). This list assignment was counterbalanced across participants so that each list was present in all item types.

At study, 96 word pairs and six buffer pairs were presented (three buffer pairs at the beginning and three at the end of the list). At test, 120 items were presented, including 24 new pairs, which were composed of nonstudied words (X–X); 48 rearranged pairs, which were made of studied words rearranged to form new pairings (A–D or C–B); and 48 intact pairs, which consisted of the previously studied pairs (A–B or C–D). The 7-letter and 6-letter words were presented on the left and right sides, respectively. Two practice phases were included, one using descriptions of all possible test items and one using buffer items. At all phases, pairs were presented in a random order.

Procedure. The procedure at study was identical to that used in Experiment 1 with the exception that sentences generated by participants were recorded. On average, the study phase was 12.2 min for younger adults and 12.3 min for older adults, $t < 1$. Younger and older participants were successful in creating sentences for 95% and 94% of the word pairs, respectively, $t < 1$.

After the study phase, participants performed an associative recognition test. They were instructed to respond quickly and accurately. First, participants were asked if they had seen the presented word pairing during the study task. That is, participants had to respond "old" only to intact pairs. Participants keyed in their "old" and "new" responses with their left and right index fingers using the v and m keys. The response-key mapping was counterbalanced across participants. Following each old–new decision, the pair of words remained on the screen and participants were asked to try to recall the sentence that they had created during the study for pairs that they identified as being old, or were asked to recall the original paired words as well as the sentences that they had created during the study for pairs they believed were new but rearranged in a novel way. They were also instructed to inform the examiner if they believed some words were never studied or if they recalled being unable to generate a sentence during the study phase. The examiner walked each participant through this procedure, and participants' verbal responses were recorded and later transcribed and scored. The old–new scores were adjusted in cases wherein participants self-corrected their answer at the time of the associative information recall (recall of words or sentences). These adjustments did not improve the accuracy on rearranged pairs and only slightly improved it on intact pairs (a gain of 2.2% for young adults and 1.6% for older adults). The Vocabulary subtest of the Shipley Institute of Living Scale and the MMSE (older adults only) were administered at the end of the testing session.

Results

The raw proportions of "old" responses to new, rearranged, and intact pairs are presented in Table 3. From these, we derived the associative identification measure as well as performance on rearranged pairs (recall-to-reject) and intact pairs (recall-to-accept). We also obtained accurate measures of recall-to-reject and recall-to-accept by asking participants to recall a particular type of associated information (e.g., paired word for rearranged items and sentence for intact pairs). These scores are presented in Table 4. We tested group differences separately on all of the measures listed above using t tests. To investigate the presence of an age-

Table 3
Mean (SD) Proportion of "Old" Responses for Each Item Type and Associative Identification Measure for Experiment 2

Group	New	Rearranged	Intact	Associative identification (d')
Younger	.00 (.02)	.10 (.09)	.84 (.11)	2.54 (0.73)
Older	.05 (.07)	.24 (.17)	.65 (.19)	1.25 (0.54)

related disproportionate decline between recall-to-reject and recall-to-accept ability we computed 2 (young, old) × 2 (correct rejections to rearranged pairs, hits to intact pairs) and a 2 (young, old) × 2 (paired-word recall, sentence recall) repeated measures analyses of variance. To investigate whether poor recollection was the key reason underlying age-related deficits in associative identification, we computed two analyses of covariance: In the first one, we tested for age-related differences in the correct rejections of rearranged pairs when the raw paired-word recall was used as a covariate; in the second, we tested for age-related differences in hits to intact pairs when raw sentence recall was used as a covariate.

Associative identification and "old" responses to rearranged and intact pairs. A d' score indexing associative identification was derived from the hit rates to intact pairs and false alarm rate to rearranged pairs. As reported in Table 3, associative identification was impaired in the older group, $t(46) = 6.97$, $p < .001$, $d = 2.04$; this was related to a mirror effect, that is, elevated false alarm rates to rearranged pairs, $t(46) = 3.08$, $p < .01$, $d = 0.91$, and reduced hit rate to intact pairs, $t(46) = 4.91$, $p < .001$, $d = 1.47$. These were affected to a similar extent in the older group (interaction, $F < 1$, partial $\eta^2 = .01$).

Paired-word and sentence recall. We obtained more precise and accurate measures of recall-to-reject and recall-to-accept: paired-word recall[4] and sentence recall, respectively. Paired-word recall was obtained by requiring participants to recall the studied associates of words composing correctly rejected rearranged pairs. An accurate recall included trials for which the associate, or its synonym, of at least one of the two words was recalled. Sentence recall was obtained by requiring participants to recall the sentence they had created at study for each intact pair identified as old. Sentences were scored as accurate if all of the components and ideas included in the original sentence were retrieved. Thus, correct answers were not limited to verbatim recall and could contain synonymous substitutions, as well as changes in verb tense, grammatical structure, and order of words. Accurate recalls also included instances in which participants recalled that they had failed to create a sentence at study (younger: $M = 0.58$ items; older: $M = 0.38$ items). Sentences were scored by two independent raters with high interrater reliability ($r = .986$, $p < .001$).

As shown in Figure 4, age-related impairments were found on both the paired-word recall, $t(46) = 6.71$, $p < .001$, $d = 2.00$; and sentence recall measures, $t(46) = 2.40$, $p < .05$, $d = 0.70$; but the paired-word recall was significantly more compromised than was the sentence recall: interaction, $F(1, 46) = 27.31$, $p < .001$, partial $\eta^2 = .37$.

Does poor recollection underline age-related associative identification deficits? To test whether a general recollection deficit was to blame for the age-related deficits in associative identification, we computed analyses of covariance to reanalyze the correct rejection rate to rearranged pairs using the paired-word recall as a covariate and the hit rate to intact pairs using the sentence recall as a covariate. Age-related differences in correct rejections to rearranged pairs ($F < 1$, partial $\eta^2 = .02$) and in hit rates to intact pairs, $F(1, 45) = 2.26$, $p = .14$, partial $\eta^2 = .05$, were no longer present, suggesting that poor recollection was a key component explaining age-related deficits in associative identification.

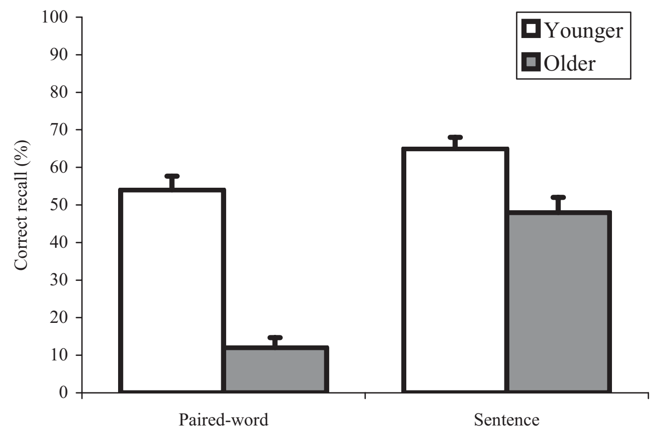

Figure 4. Accurate recall-to-accept and recall-to-reject measures in younger and older adults with standard error in Experiment 2.

Table 4
Frequencies (SD) of Study Variables for Experiment 2

Group	Raw hits to intact pairs	Raw accurate sentence recall	Raw correct rejections of rearranged pairs	Raw accurate paired-word recall
Younger	40.1 (5.4)	26.2 (7.2)	43.4 (4.1)	21.1 (10.6)
Older	31.1 (9.1)	16.9 (7.9)	36.4 (7.9)	4.8 (5.3)

Discussion

Results from Experiment 2 support the general recollection deficit hypothesis. Data from the old–new judgments revealed a mirror effect (i.e., equally impaired ability to reject familiar lures and to endorse studied pairs), and impairments were noted with respect to the information underlying accurate recall-to-reject (i.e., paired-word recall) as well as recall-to-accept (i.e., sentence recall), though the deficit was more prominent in the former condition. The most telling evidence supporting a general recollection deficit comes from the results of the analysis of covariance. By covarying performance with the number of words recovered in the "recombined" condition and sentences recovered in the "intact" condition, we eliminated age differences on the associative recognition task.

In sum, when recollection is used by younger adults, either to augment their performance on intact pairs (recall-to-accept) or rearranged pairs (recall-to-reject), age-related declines are evident, suggesting that the recollected information is not comparable across age groups and indicates a mild, overall reduction in recollection. Our data also suggest that strategic retrieval deficits amplify this general deficit in recollection, given that older adults showed a greater impairment in recalling the correct words in the rearranged condition than recalling the sentences in the intact

[4] Paired-word recall was selected as the recall-to-reject measure over the ability to recall the sentences associated with one of the words contained in the rearranged pairs. We selected this measure because it provides sufficient information to apply a recall-to-reject strategy and is more liberal (i.e., the paired word or one of its synonyms must be included in the sentence to be scored as accurate).

condition. In the rearranged condition, the cues are not as informative as in the intact pairing condition, and therefore, strategic retrieval processes are required (e.g., cue specification and elaboration).

Results from Experiment 2 were different from those in Experiment 1, for which no group differences were observed on the hit rate to intact pairs, which suggests intact recall-to-accept. As we speculated, recalling associated information encouraged young participants to use recollection, even in the intact pair condition (recall-to-accept), which enhanced their hit rate relative to Experiment 1. What is particularly interesting is that older adults did not benefit from this instruction, which is consistent with Healy et al.'s (2005) findings but contrasts with findings showing greater gains in older adults (Naveh-Benjamin et al., 2007). Our task, however, included more items than used in the latter study, and the difference in findings may be due to differences in interference.

Another important finding is that even in young adults, recovery of the studied information in each condition is far from perfect. For a substantial portion of their correct responses, the participants could not recall the words or the sentences. This means that in many cases they relied more on "negative" knowledge (e.g., distinctiveness heuristics)—namely, they knew that the two rearranged words were not studied together without being able to retrieve the correct associate. The process or strategy that underlies hits to intact pairs for which participants fail to recall the associative information remains unknown. Participants may rely on partial recall of the associative information that is not sufficient to be scored as accurate or on a sense of familiarity for the association. This type of familiarity may be the same as that underlying associative reinstatement in Experiment 1.

General Discussion

The major goal of the present study was to compare older and young adults' performance on different associative memory measures to test the contribution of strategic retrieval processes to the age-related deficit in associative memory. Our main finding was that of a disproportionate age-related decline across these measures. Older adults were able to retrieve associative information when the test conditions were minimally demanding in terms of self-initiated retrieval processes (associative reinstatement and some recall-to-accept measures), but they failed to retrieve this information in situations that were highly demanding on such processes (associative identification, recall-to-reject, and recall-to-accept if it relied to a substantial extent on recollection, as it did in Experiment 2).

In Experiment 1, the associative identification measure was deficient in the older group due to an impaired ability to reject familiar lures, suggesting poor recall-to-reject abilities, whereas endorsing intact pairs was intact, suggesting that recall-to-accept abilities are less affected by aging. Similarly, older adults used associative information to the same extent as did young adults to enhance their item memory, both in terms of speed and accuracy, as shown on associative reinstatement measures. In Experiment 2, in which recollection was promoted in all conditions, there were equivalent impairments in the hit rates to intact pairs and false alarm rates to rearranged pairs. Even then, the more precise measure of recall-to-reject (paired-word recall) was severely reduced in older adults, whereas recall-to-accept (sentence recall) was less problematic, though still compromised.

These data have interesting implications on how researchers conceptualize the age-related deficit in associative memory. We address these in relation to the binding, general recollection, and the strategic retrieval failure hypotheses and to a cognitive–neurobiological model of associative memory and aging.

Binding Hypothesis

Our results suggest that a deficit in binding at encoding (Chalfonte & Johnson, 1996; Naveh-Benjamin, 2000; Naveh-Benjamin et al., 2003) is not sufficient to explain age-related deficits in associative memory. Evidence that associative reinstatement and, under some conditions, even recall-to-accept, is not impaired in older adults indicates that older adults can form associations and use them to facilitate item memory retrieval (associative reinstatement) and endorse intact pairs in some situations (recall-to-accept). By contrast, older adults are impaired on the associative identification measure due to poor recall-to-reject abilities under all conditions, and even on recall-to-accept if recollection plays a prominent role.

We believe that the type of binding underlying intact associative reinstatement measures is not the same as that underlying implicit memory tasks (e.g., associative priming). Associative reinstatement effects were not found in amnesic patients with medial temporal lobe lesions despite these patients' intact performance on implicit tests of associative memory (Goshen-Gottstein, Moscovitch, & Melo, 2000) or in young adults under a shallow encoding manipulation (Cohn & Moscovitch, 2007). In the latter study, associative reinstatement was enhanced with depth of encoding, which contrasts with a well-known characteristic of implicit memory, that is, that it benefits little, if at all, from such encoding. Furthermore, the magnitudes of the effects are atypical for priming measures, particularly that of the response speed gain, which is approximately 300 ms, whereas the associative priming advantage is on the order of 50 ms. Thus, the associative reinstatement effects do not represent instances of nondeclarative memory processes contributing to explicit tasks but rather index a process pertaining to declarative memory.

We also believe that preserved binding of associative information supported older adults' ability to endorse intact pairs in Experiment 1. In young adults, hit rates for intact pairs can be maintained at a high level only if associative information is bound at encoding or if item memory is increased to compensate for reductions in associative memory (Cohn & Moscovitch, 2007). Given that item memory was reduced in the older group, it could not have compensated for a deficit in binding in the current study.

The results from Experiment 2 support these conclusions. Although encoding conditions, and presumably the extent of binding, remained the same as in Experiment 1, retrieval conditions changed by requiring participants to recover the associative information at each trial. This change led to an age-related deficit in recall-to-accept, presumably because younger adults, but not older ones, could benefit to a greater extent from increases in strategic retrieval and recollection processes that our manipulation induced. Thus, keeping encoding and binding the same, we were able to produce an age-related deficit in recall-to-accept where there had been none before. Thus, though binding may be impaired in older adults, their associative memory loss is also a function of deficient self-initiated retrieval processes.

As in retrieval, impaired strategic processes may contribute to poor binding at encoding. Support for this includes evidence showing greater age-related associative memory deficits following intentional rather than incidental encoding instructions, qualitative differences in reported encoding strategies (Naveh-Benjamin, 2000; Naveh-Benjamin et al., 2007; but see Dunlosky & Hertzog, 1998), and improved performance on an associative identification test in older adults when instructed to use a deep relational encoding strategy (Naveh-Benjamin et al., 2007).

This poor use of encoding strategies can also account for findings showing that aging can have a detrimental effect on associative reinstatement (Bayen et al., 2000; Castel & Craik, 2003), contrary to the findings in the present study. Whereas we equated the encoding strategy used across groups by imposing a sentence generation task that optimized binding, no relational encoding task was given in the Bayen et al. and Castel and Craik studies; participants were simply instructed to remember the information for a later memory task. This type of study instruction was compared to the sentence generation task in a previous experiment with young adults (Cohn & Moscovitch, 2007) and resulted in reduced associative reinstatement and associative identification, a pattern similar to that seen in the older participants in the Castel and Craik study.

In sum, our data are inconsistent with a pervasive binding deficit. Binding may be reduced, but not absent, and may be problematic predominantly in situations in which older adults must implement their own encoding strategies.

Recollection Hypothesis

Our results are also not entirely consistent with a severe general recollection deficit, because such a deficit should equally and consistently affect recall-to-reject and recall-to-accept measures. Older adults' elevated false alarm rates to rearranged pairs on the associative recognition task in both experiments, and their markedly impaired recall of the original paired associate of words composing rearranged pairs in Experiment 2, confirm that at least one variant of recollection, namely recall-to-reject, is reliably and severely compromised in aging. In contrast, recall-to-accept appears less affected. This was evidenced by older adults' normal hit rates to intact pairs on the associative recognition task in Experiment 1 and their less severe deficit on sentence recall as compared to paired-word recall in Experiment 2. Together, our results are consistent with previous associative memory studies showing that older adults' deficits are greater and sometimes solely present on the rearranged pairs relative to the intact pairs (Castel & Craik, 2003; Healy et al., 2005). If, however, the use of recollection is encouraged for intact pairs, as in Experiment 2, then older adults are less able than younger adults to take advantage of that situation.

In sum, overall recollection is at least mildly reduced in aging, and this reduction is noticeably amplified on measures that place high demands on strategic retrieval processes. In other words, older adults can recollect associative information more effectively when provided with good memory cues, but they fail when the task requires more strategic retrieval processes (e.g., cue elaboration and specification). Thus, a problem in the self-initiated access to recollective experience is a crucial characteristic of the effect of aging on memory function and supplements an overall reduction in recollection.

Strategic Retrieval Hypothesis

The uneven decline with age between associative memory measures that differentially rely on the instantiation of retrieval processes is consistent with the retrieval failure hypothesis. Indeed, this pattern of results, and especially our finding of intact associative reinstatement, is similar to that obtained with young adults under conditions in which there is interference with recall-like processes at retrieval (e.g., deadline, speeded and overlapping pairing manipulations), but not with that obtained under conditions that hamper or interfere with relational processing or binding at encoding (Cohn & Moscovitch, 2007). Furthermore, the disproportionate decline in aging on measures of recall-to-reject, as compared to recall-to accept, is also concordant with other studies (Castel & Craik, 2003; Healy et al., 2005) and supports the retrieval failure hypothesis. As noted at the beginning of this article, these two measures vary in terms of their reliance on self-initiated retrieval processes because their respective test trial types provide memory cues that are of different quality. For recall-to-reject, rearranged pairs only provide item information, and this partial cue must be elaborated to retrieve the associative information. In contrast, for recall-to-accept, intact pairs reinstate both the items and the associative information, which constitutes a more efficient cue because it closely matches the stored memory representation.

In sum, older adults are able to encode associative information and retain it sufficiently to support some recall-to-accept and reinstatement measures, but they have difficulty accessing this information voluntarily when memory search cues are poor. This forces them to depend on their own, presumably reduced, retrieval strategies and to rely more on their relatively preserved item familiarity. However, they can retrieve this associative information more efficiently if adequate support is provided to them at retrieval (e.g., good memory cues). This observation is reminiscent of Craik's (1986) suggestion that older adults have difficulty reinstating the original context on their own but can still benefit from the environmental support that reinstates it for them. It is also consistent with evidence showing that older adults use less effective memory search cues in a paired associate paradigm relative to young adults (Micco & Masson, 1992).

Cognitive–Neurobiological Model of Associative Memory and Aging

Overall, our data support a joint binding, recollection, and retrieval failure hypothesis, with the retrieval failure having the greatest impact under the conditions of these experiments. The idea is consistent with Henkel, Johnson, and De Leonardis's (1998) suggestion that age-related deficits in *source memory*, a type of associative memory, arise from difficulty assembling and reassembling elements of complex representations. This interpretation is derived from Johnson's source memory framework, which stresses the importance of processes involved in feature binding at encoding and in complex evaluation and criteria setting at retrieval (Johnson, 1992; Johnson, Hashtroudi, & Lindsay, 1993).

These cognitive frameworks are consistent with neurobiological models of episodic memory that attribute crucial and distinct roles to frontal and medial temporal lobes (MTL; Moscovitch, 1992; Simons & Spiers, 2003). Frontal regions are involved in strategic processes; they direct attention and organize information at encoding, initiate and guide retrieval, and monitor and verify the retrieved information. MTL automatically picks up information, binds elements to form a memory trace, obligatorily and effortlessly recovers the information when the proper memory cue is used, and, thus, supports the conscious reexperiencing or recollection of the memories. Given that atrophy is prominent in frontal lobes in aging and is also present in MTL (Alexander et al., 2006; Raz et al., 1997, 2005; Raz, Rodrigue, Head, Kennedy, & Acker, 2004), it makes sense that binding, recollection, and strategic processes both at encoding and retrieval are deficient in aging. Support for this view includes studies showing that older adults' source memory and recollection scores are related to frontal and MTL indices derived from standardized neuropsychological tests (frontal only: Glisky, Polster, & Routhieaux, 1995; Glisky, Rubin, & Davidson, 2001; frontal and MTL: Davidson & Glisky, 2002; Henkel et al., 1998).

Thus, the volitional access to associative information seems reduced in aging due to co-occurring frontal and MTL dysfunction. In the current experiment, the strategy imposed at encoding (sentence generation) and the provision of good retrieval cues (intact pairs) may have minimized the impact of the frontal dysfunction, leaving only a slight age-related deficit in recall-to-accept abilities that may reflect a mild MTL dysfunction. Although this view accounts for deficits in binding, recollection, and strategic abilities, it cannot account for older adults' intact associative reinstatement given that it is dependent on MTL functional integrity. This assumption is based on evidence showing impaired associative reinstatement in patients with MTL lesions (Cohn, McAndrews, & Moscovitch, 2007; Goshen-Gottstein et al., 2000).

There are two ways to account for older adults' intact associative reinstatement in light of their impairments on other associative memory measures. First, their associative memory deficits may be due solely to impaired frontal function, whereas MTL functions are intact, and the degree of impairment is proportional to the demands each task places on strategic retrieval processes. We can argue, then, that associative reinstatement places no such demands and is thus intact, recall-to-accept places minimal demands and is slightly impaired, and recall-to-reject places high demands and is severely compromised. The other way is to consider that subregions of the MTL, namely the hippocampus and rhinal cortex, support different representations of associative information and are unevenly affected by the aging process, with greater atrophy in the hippocampus relative to the rhinal cortex (Raz et al., 2004, 2005). According to recent proposals, the rhinal cortex supports unitized (e.g., compound words; Quamme, Yonelinas, & Norman, 2007) or intradomain associations (e.g., word–word pairs; Mayes, Montaldi, & Migo, 2007) via familiarity, and the hippocampus mediates associations based on recollection. These proposals were tested only using associative identification measures, and it is unclear whether the bound associations that underlie our associative reinstatement measure and those that underlie other associative memory measures are mediated by the same structures. Additional studies are required to test this idea.

Conclusion

Our results show that strategic retrieval processes contribute to age-related associative memory loss and that this deficit, above and beyond poor binding of items, leads to and amplifies impairment in recollection. When demands on such processes are minimal, as in tests of associative reinstatement (and associative priming), age-related deficits are absent, but when they are high, as in tests of associative identification, the deficits are substantial. Although strategic retrieval is needed for recollection, our findings suggest that deficits in recollection alone cannot account for all aspects of performance (e.g., uneven declines between recall-to-reject and recall-to-accept measures). These strategic retrieval deficits are possibly related to frontal lobe dysfunction that accompanies old age, whereas deficits in binding and recollection are likely related to decline in both MTL (most likely hippocampal) and frontal lobe functions. Importantly, those associative memory functions that are spared in older adults, such as associative reinstatement and associative priming, are mediated by other structures, most probably the rhinal cortex and posterior neocortex, respectively.

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Received March 22, 2007
Revision received July 8, 2007
Accepted July 30, 2007 ■