Effects of repetition and response deadline on associative recognition in young and older adults

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The present study examined the joint effects of repetition and response deadline on associative recognition in older adults. Young and older adults studied lists of unrelated word pairs, half presented once (weak pairs) and half presented four times (strong pairs). Test lists contained old (intact) pairs, pairs consisting of old words that had been studied with other partners (rearranged lures), and unstudied pairs (new lures), and participants were asked to respond "old" only to intact pairs. In Experiment 1, participants were tested with both short and long deadlines. In Experiment 2, the tests were unpaced. In both experiments, repetition increased hit rates for young and older adults. Young adults tested with a long deadline showed reduced (Experiment 1) or invariant (Experiment 2) false alarms to rearranged lures when word pairs were studied more often. Young adults tested with a short deadline and older adults tested under all conditions had increased false alarm rates for strong rearranged pairs. Implications of these results for theories of associative recognition and cognitive aging are explored.

According to dual-process models of memory, there are two processes—recollection and familiarity—that underlie recall and recognition (e.g., Atkinson & Juola, 1974; Hintzman, 1986; Humphreys, Bain, & Pike, 1989; Jacoby, 1991; Mandler, 1980; Raaijmakers & Shiffrin, 1992; Yonelinas, 1994, 1997; see Yonelinas, 2002, for a review). Recollection is generally described as a conscious, attention-demanding process, with a slow rise-time. Recollection entails conscious retrieval of specific episodic information, including perceptual details, the source of information, temporal or spatial information, and emotions that accompany the events. Familiarity, on the other hand, is conceptualized as an unconscious, relatively automatic process that is recruited more rapidly. Item recognition appears to be based largely on familiarity, especially when lures and targets are dissimilar. However, associative recognition, in which pairs of words studied together must be discriminated from pairs whose

constituents were studied with different partners, requires recollection (Kelley & Wixted, 2001; Rotello & Heit, 1999, 2000; Rotello, Macmillan, & Van Tassel, 2000; Yonelinas, 1997).

Several lines of evidence support the idea that familiarity-based mechanisms may be relatively well preserved in old age, whereas recollection is more adversely affected (for reviews, see Light, Prull, La Voie, & Healy, 2000; Yonelinas, 2002; Zacks, Hasher, & Li, 2000, but also see Healy & Light, 2004, and Prull, 2003, for suggestions of age-related differences in familiarity). We begin by briefly summarizing some evidence that this is so. We then report two experiments that offer further support of impaired recollection and relatively preserved familiarity processes in old age using an associative recognition task.

It is widely assumed that recall depends more heavily on recollective processes than does recognition, with the latter generally based more on familiarity (e.g., Yonelinas, 2002). If aging is accompanied by greater declines in recollection with relative sparing of familiarity processes, it would be expected that aging would have more adverse effects on recall than on recognition. This prediction is borne out by the order of effect sizes in meta-analyses (e.g., La Voie & Light, 1994; Verhaeghen, Marcoen, & Goossens, 1993). In addition, even when item recognition is held constant, older adults demonstrate poorer memory for contextual information (e.g., Chalfonte & Johnson, 1996; Kliegl & Lindenberger, 1993;

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Schacter, Osowiecki, Kaszniak, Kihlstrom, & Valdiserri, 1994; Spencer & Raz, 1995). Likewise, age differences are apparent in associative recognition when young and older adults' recognition of individual items has been equated (e.g., Castel & Craik, 2003; Healy & Light, 2004; Naveh-Benjamin, 2000; Naveh-Benjamin, Hussain, Guez, & Bar-On, 2003). Older adults are also more likely than young adults to falsely identify words (e.g., *barley*) as "old" when their component syllables have been studied in other words (e.g., *barter*, *valley*); that is, they are more prone to conjunction errors (Kroll, Knight, Metcalfe, Wolf, & Tulving, 1996; Rubin, Van Petten, Glisky, & Newberg, 1999).

Evidence of impaired recollection and relative preservation of familiarity has been found with other paradigms as well (see Light et al., 2000, for a review). For example, older adults are more susceptible to source errors due to familiarity in the absence of recollection in the false-fame paradigm; that is, they are more likely to call a previously studied nonfamous name "famous" on a subsequent test (Bartlett, Strater, & Fulton, 1991; Dywan & Jacoby, 1990; Jennings & Jacoby, 1993). Older adults show higher false alarm rates in recognition and intrusion rates in recall than young adults after studying lists of items that are semantically or phonologically associated with target words or concepts, a form of memory illusion (e.g., Balota et al., 1999; Koutstaal & Schacter, 1997; Norman & Schacter, 1997; Tun, Wingfield, Rosen, & Blanchard, 1998). Moreover, older adults are more likely to make false alarms to lures repeated at test (Dodson & Schacter, 2002; Dywan, Segalowitz, & Webster, 1998; Jennings & Jacoby, 1997; Koriat, Ben-Zur, & Sheffer, 1988).

Using a process dissociation paradigm, Jacoby (1999) investigated the influence of both repetition and response pressure in the context of aging. Participants saw a list in which some words appeared one, two, or three times, and then heard a second list of words. At test, they were asked to respond "old" only to words they had heard. When younger adults were given long response deadlines, false alarms to previously studied words decreased with repetition. Ironically, false alarms to previously studied words increased with repetition for older adults, even with quite long deadlines. Thus, for younger adults, exclusion of seen words improved as a function of repetition, but the opposite was true for older adults, consistent with an age-related deficit in the use of contextual information—that is, recollection—to oppose enhanced familiarity produced by repetition. Interestingly, young adults also showed an increase in false alarms with repetition when forced to respond quickly; this finding accords well with the view that recollection has a longer rise-time than familiarity.

Similar ironic effects of repetition for older adults and for young adults tested with short response deadlines have been found for the Deese/Roediger-McDermott task (Benjamin, 2001; Budson, Daffner, Desikan, & Schacter, 2000; Kensinger & Schacter, 1999; Watson, McDermott, & Balota, 2004) as well as in the false-fame

paradigm (Bartlett et al., 1991). Furthermore, Benjamin and Craik (2001) found a related effect of massed versus spaced repetition—separating two presentations of an item rather than giving them consecutively led young adults to correctly endorse the item more often when asked to recognize it and to reject it when instructed to exclude it. However, older adults and young adults responding under time pressure did not benefit from spaced repetition when asked to exclude items. Such findings are easily explained by the assumption that familiarity is less effectively opposed by recollection in older adults and in young adults who are pressured to respond quickly.¹

In the present study, we asked whether these findings could be generalized to associative recognition. We utilized a paradigm previously employed by Kelley and Wixted (2001) in which young adults studied lists of word pairs. Half of the pairs were presented once (*weak* pairs), and half were presented four times (*strong* pairs). After study, participants were given a recognition test that included strong and weak intact pairs (both words studied together), strong and weak rearranged pairs (both words studied but with different partners), and new pairs. Kelley and Wixted found that with repetition of pairs at study, young adults' hits to intact pairs increased, while their false alarms to rearranged pairs remained constant. One explanation of their findings is that both familiarity and recollection are increased by repetition of study pairs. For intact pairs, familiarity and recollection work in concert to boost hit rates. Although rearranged lures become more familiar with repetition, young adults may recollect the original pairs and reject these lures, successfully opposing the (here misleading) effects of familiarity. However, if recollection fails and both items of a test pair are familiar, participants respond "old," producing false alarms to rearranged lures.

Phenotypically similar results in young adults have been reported by Jones and Jacoby (2001) for compound words (e.g., *blackbird*) whose constituents were studied in other compounds (e.g., *blackmail*, *jailbird*). In addition, Jones and Jacoby found that with short response deadlines, young adults had increased false alarm rates for conjunction lures. Because compound words may be processed as conceptual units, rather than as two separate concepts conjoined by an association, with the effects of prior experience occurring at a lexical or sublexical level (cf. James & Burke, 2000; Tehan & Humphreys, 1998), it is not clear whether the Jones and Jacoby results will replicate with word pairs. There is reason to believe that they will, because Cleary, Curran, and Greene (2001) observed a similar outcome in the context of a frequency judgment task for repeated word pairs—judgments that an intact pair had never occurred in the study list decreased systematically with repetitions, whereas judgments that rearranged pairs had not occurred either was nearly constant over 12 repetitions or showed little increase after 5 repetitions. The experiments reported here are designed to shed further light on this issue in a more standard associative recognition task.

Table 1
Means for Young and Older Participants on Selected Measures

Measure	Experiment 1				Experiment 2			
	Young		Old		Young		Old	
	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>
Years of education	13.62	1.30	15.09*	3.21	13.32	1.64	15.58**	2.45
Subjective health rating ^a	8.35	0.73	7.30**	1.86	8.05	1.36	7.97	1.47
Word fluency ^b	14.47	3.19	13.32	3.84	14.29	4.18	14.21	2.81
Vocabulary ^c	15.92	3.62	17.97	4.90	15.61	4.17	19.39**	3.45
Reading span ^d	3.50	1.53	2.17**	0.87	3.06	1.69	1.94**	0.75
Computation span ^d	3.31	1.59	2.40*	0.93	3.10	1.14	2.42**	0.79
Circling As ^{e, f}	17.96	3.24	13.80**	3.14	17.87	3.10	14.14**	2.96
Digit–digit (msec) ^g	543.42	73.11	772.77**	143.65	608.87	72.31	789.30**	109.70
Digit–symbol (msec) ^g	1,201.38	304.49	1,777.80**	347.77	1,241.67	130.99	1,725.88**	301.97
WCST categories correct ^h	5.77	0.43	4.77**	1.55	5.71	0.78	4.67**	1.80
WCST perseverative errors	6.54	6.15	12.40**	8.10	6.39	6.49	13.00**	11.51

^a1 = *poor*; 10 = *excellent*. ^bMean number of words generated beginning with the letters C, F, and L in 60 sec.

^cMaximum = 25. ^dMaximum = 7. ^eMean number of As circled per minute. ^fData for *n* = 26 young adults in Experiment 2. ^gMedian latency per trial. ^hMaximum = 6. **p* < .05. ***p* < .01.

In Experiment 1, word pairs were presented once (weak pairs) or four times (strong pairs), and participants were tested under both long and short deadline conditions. We predicted that without pressure to respond quickly, young adults would show the pattern of results found by Kelley and Wixted (2001) for word pairs and by Jones and Jacoby (2001) for compound nouns—to wit, higher hit rates for strong than for weak pairs, but no effect of repetition on false alarms to rearranged lures. We also predicted that young adults would show an increase in false alarms to rearranged lures whose members had been studied in strong pairs when pressured to respond quickly (short deadline). Older adults, in contrast, should show ironic effects of repetition manifested as higher rates of false alarms to strong than to weak rearranged lures in both short and long deadline conditions. To preview our findings, this was what we found. In Experiment 2, responding was self-paced. The question of interest was whether giving older adults unlimited time to respond would encourage recruitment of recollection to oppose familiarity, yielding a pattern of results like that of young adults in the long deadline condition of Experiment 1.

EXPERIMENT 1

Method

Participants. Young participants in both experiments were students recruited from the Claremont Colleges. Older adults were recruited from the Claremont area. All participants were paid \$20 for participation. Thirty-two young and 36 older adults participated in Experiment 1. The data from 6 young participants were excluded, 3 because of experimenter error and 3 because they gave responses of “old” to all new pairs in one or both deadline conditions (suggesting a misunderstanding of the task). The data from 6 older participants were also excluded, 2 due to experimenter error; of the remaining 4, 1 was not a native speaker of English, 1 performed below criterion level in several auxiliary tasks, and 2 were unable to perform the speeded recognition task. Thus, 26 young (7 men, 19 women) and 30 older (13 men, 17 women) participants are represented in the analyses reported here. The mean ages of the two groups were 19.85 (*SD* = 2.29, range = 18 to 27) and 69.13 (*SD* = 4.77, range = 61 to 78), respectively. Addi-

tional background information for these participants is given in Table 1.

Design and Materials. Stimulus presentation and data collection were controlled with PsyScope (Cohen, MacWhinney, Flatt, & Provost, 1993). Stimuli were presented on a 17-in. monitor in uppercase 18-point Geneva font. For practice, participants studied two lists of 25 pairs of words selected from the MRC Psycholinguistics Database (Coltheart, 1981). Five of these word pairs were presented once (weak pairs) and another five were presented four times (strong pairs). After each study list, the participants were given a recognition test (at one of two deadlines, as described below) that consisted of 5 intact pairs—studied pairs reappearing at test (2 or 3 weak, 2 or 3 strong), and 10 rearranged pairs—both words studied but with different partners (5 weak, 5 strong), and 10 new pairs that had not appeared previously in the experiment. The shorter deadline study–test practice block preceded the longer deadline practice for all participants.

After studying the practice lists, the participants studied two lists of 44 word pairs. Words were selected from the MRC Psycholinguistics Database (Coltheart, 1981). Words varied in length between 4 and 9 letters and had a mean frequency of 43.74 occurrences per million (range = 1 to 500; Kučera & Francis, 1967). Twenty of these word pairs were presented once (weak pairs) and 20 were presented four times (strong pairs). The remaining four pairs served as recency and primacy buffers (two each). After each study list, the participants received a recognition test (either longer or shorter deadline) that consisted of 20 intact pairs (10 weak, 10 strong), 20 rearranged pairs (10 weak, 10 strong), and 20 new pairs.

Assignment of words to word pairs and word pairs to testing condition was randomized for each participant. Within a study list, repetitions of word pairs in the strong condition were separated by a minimum of one other pair. Each participant was tested with both longer and shorter deadlines, with order of deadline conditions counterbalanced across participants in each age group.

Procedure. The participants first read detailed instructions about the experiment. They were told that they would study two lists of word pairs with a memory test after each one. The instructions clearly described the three types of test pairs that would appear. In particular, the participants were told that the test pair types were *intact* pairs, *rearranged* pairs, and *new* pairs, that they should respond “old” only to intact pairs, that old and new words were never paired together, that any words repeated at test were on the same side of the screen as in the study block, and finally, that words only appeared within one study–test block. Telling the participants about the types of pairs that they would encounter on the recognition test, especially

the difference between intact and rearranged word pairs, was expected to foster the use of recollection (Jones & Jacoby, 2001). No mention was made of particular encoding strategies, such as forming associations between the words. In other research, we have found improved associative recognition in young, but not older, adults following strategic encoding instructions (Healy & Light, 2004). The presentation rate for the study lists was 3 sec per pair.

On each test trial, the participants were shown a focal stimulus (+++++) for 500 msec, followed by the presentation of the test word pair. Three deadline conditions were used—short, long, and extra long—with young adults tested in the first two and older adults in the last two. In the short deadline condition, a response cue (*****) appeared beneath the test pair 400 msec after presentation. The participants then had 600 msec to respond. The end of this response window was signaled by a beep, and a 1,000-msec intertrial interval (blank screen) began immediately thereafter. Thus, each trial lasted 2,500 msec, even though test pairs disappeared from the screen if a response occurred within the response window. All responses were recorded, regardless of whether or not the deadline was met. In the long deadline condition, the response cue did not appear until after the test pair had been shown for 2,400 msec. Durations of all other events within the trial were the same as in the short deadline condition, and each trial lasted 4,500 msec. In the extra-long deadline condition, the response window was increased to 1,600 msec. Therefore, each extra-long deadline trial lasted 5,500 msec. Thus, the shorter of the two deadlines used with older adults was made identical to the longer of the two deadlines used with young adults to compensate for general slowing that occurs with age (see Jacoby, 1999, for a similar design).

The participants judged whether the test pair was *old* or *new* with a 6-point scale (1 = *sure new* to 6 = *sure old*). They were encouraged to use the entire scale in their responses. Responses were made by pressing the c, v, b, n, m, and , keys on the keyboard, labeled 1, 2, 3, 4, 5, and 6, respectively.

The two associative recognition blocks were separated by an interval of approximately 6 min, during which a word fluency task and a locally developed measure of perceptual-motor speed (circling As) were administered. Several additional tasks were also given at the beginning and end of the experiment to more fully characterize our samples and for other reasons unrelated to the present report. Table 1 gives young and older adult means for the two measures named above as well as for vocabulary (25 items selected from Nelson and Denny, 1961), computation span and sentence span tasks (measures of working memory adapted from the computerized versions developed by Salthouse, 1992), digit–digit and digit–symbol comparison tasks (measures of perceptual motor speed also adapted from Salthouse, 1992), and two measures derived from a computerized version of the Wisconsin Card Sorting Test (WCST; Keller & Davis, 1998).

Results

We began by examining the probability of a time-out (failure to respond within the response window). A 2×2 (age $\times$ deadline [shorter vs. longer for each age group]) analysis of variance (ANOVA) yielded a significant two-way interaction between age and deadline [$F(1,54) = 8.75, p < .01$, partial $\eta^2 = .14$]. Both young and older participants had significantly higher rates of responses outside of the response window in their shorter than in their longer deadline condition. The difference in time-out rates for these two conditions was smaller for young adults [$M_s = .09$ and $.04, t(25) = 4.18, p < .01$], than for older adults [$M_s = .12$ and $.01, t(29) = 6.71, p < .01$]. Given these age differences in time-outs, we analyzed recognition judgments in two ways, first using all responses made by the participants, regardless of whether

these fell within the response window, and also conditionalizing on deadline, with only responses falling within the designated time limit included in the computations. The two approaches yielded the same patterns of significant outcomes. Therefore, for the sake of brevity, only results obtained from the conditionalized responses are presented. An alpha level of .05 was used for all statistical tests, and effect sizes are reported with partial η^2 .

Old items receiving judgments of 4, 5, or 6 were designated as *hits*, whereas lures (both rearranged and new) receiving judgments of 4, 5, or 6 were designated as *false alarms*. The analyses focused on three contrasts. First, we examined performance of young and older adults at their common deadline (long). Second, we looked at the effect of pressure to respond quickly on young adults. Third, we examined the performance of older adults at their two deadlines to see whether increasing time to respond led to decreased false alarms to rearranged lures. As will be shown, the analyses confirm the findings manifest in Figure 1. The results demonstrated an ironic effect of repetition (Jacoby, 1999). Young and older adults showed a significant increase in hits with repetition in both deadlines. Young adults showed an increase in false alarms to rearranged pairs with repetition in their shorter deadline condition, but a decrease in their longer deadline condition. Older adults, however, showed increases in false alarms to rearranged lures in both their shorter and longer deadline conditions.

Comparing young and old at the same deadline. The longer deadline for young adults and the shorter deadline for older adults were the same (4,500 msec). Separate 2 (age) $\times$ 2 (strength) ANOVAs were carried out on hits and false alarms to rearranged pairs for this common deadline. Hit rates were higher for young adults ($M = .81$) than for older adults ($M = .72$) [$F(1,54) = 5.02, p < .03, \eta^2 = .09$], and higher for strong pairs ($M = .90$) than for weak pairs ($M = .64$) [$F(1,54) = 90.08, p < .01, \eta^2 = .63$]. The interaction between these variables was not significant [$F(1,54) = 2.06, p = .16, \eta^2 = .04$]. False alarm rates for rearranged pairs were higher in older adults ($M = .46$) than in young adults ($M = .21$) [$F(1,54) = 19.55, p < .01, \eta^2 = .27$]. The interaction of age with strength was also significant [$F(1,54) = 9.94, p < .01, \eta^2 = .16$]. False alarms for rearranged pairs in young adults decreased from .26 to .15 with repetition [$t(25) = 3.24, p < .01$]. Older adults showed an ironic effect of repetition, with false alarms going up from .40 for weak rearranged pairs to .51 for strong rearranged pairs [$t(29) = -1.91, p < .04$, one-tailed test].

False alarms to new lures were also greater in older adults ($M = .15$) than in young adults [$M = .05, t(54) = 2.28, p < .03$]. To investigate whether the significance of age differences in hits and false alarms to rearranged lures was affected by age differences in false alarm rates to new lures, the hit rate and the false alarm rate for rearranged pairs were corrected by subtracting from them the false alarms to new items for the appropriate age group, and the analyses discussed above were repeated for the corrected measures. The patterns of significant

Figure 1. Mean proportions of "old" responses (+SE) of young and older adults as a function of repetition and response deadline in Experiment 1.

and nonsignificant effects were identical in these analyses to those already described. Thus, when response deadline is equated across age, there is clear evidence that repetition affects young and older adults differently in associative recognition. We turn now to the effects of deadline for young and older adults.

Effects of deadline in young adults. Separate 2 (deadline) $\times$ 2 (strength) ANOVAs were carried out for hits and false alarms to rearranged lures. For hits, there were significant effects of both deadline and strength [$F(1,25) = 198.78, p < .01, \eta^2 = .89$ and $F(1,25) = 123.37, p < .01,$

$\eta^2 = .83$], qualified by their two-way interaction [$F(1,25) = 12.33, p < .01, \eta^2 = .33$]. Younger participants showed a more pronounced increase in hits with repetition at the short deadline ($M_s = .25$ and $.69$) [$t(25) = -7.92, p < .01$], than at the long deadline ($M_s = .70$ and $.92$) [$t(25) = -8.70, p < .01$]. There were more false alarms to rearranged lures at the short deadline ($M = .31$) than at the long deadline ($M = .21$) [$F(1,25) = 13.19, p < .01, \eta^2 = .35$], as well as somewhat more false alarms for strong lures ($M = .29$) than for weak lures ($M = .23$) [$F(1,25) = 3.73, p < .07, \eta^2 = .13$]. Of more interest is the two-way interaction between deadline and strength [$F(1,25) = 39.79, p < .01, \eta^2 = .61$]. Young participants showed a significant increase in false alarms with repetition in the short deadline condition ($M_s = .20$ and $.42$) [$t(25) = -4.92, p < .01$] but (as noted above) a significant decrease in the long deadline condition [$M_s = .26$ and $.15$] [$t(25) = 3.24, p < .01$].

Young participants also made somewhat more false alarms to new pair lures in the short ($M = .08$) than in the long deadline condition ($M = .05$) [$t(25) = 1.68, p = .11$]. Correcting hits and rearranged false alarms for baseline guessing by subtracting out new pair false alarm rates and repeating the ANOVAs made the main effect of deadline on false alarms to rearranged lures nonsignificant [$F(1,25) = 3.09, p = .09, \eta^2 = .11$], but left unchanged the contrast between strong and weak lures and the interaction between strength and deadline.

Effects of deadline in older adults. The same set of analyses was carried out for older adults at their two deadlines. There were, unexpectedly, more hits in the long ($M = .72$) than in the extra-long deadline condition ($M = .65$) [$F(1,29) = 8.64, p < .01, \eta^2 = .23$], and for strong intact pairs ($M = .84$) than for weak pairs ($M = .53$) [$F(1,29) = 55.17, p < .01, \eta^2 = .66$]. Of greater interest is the fact that the two-way interaction between deadline and strength was nonsignificant in the older group [$F(1,29) = .44, p = .51, \eta^2 = .02$]. Older participants showed similar increases with repetition in the long ($M_s = .58$ and $.87$) [$t(29) = -6.51, p < .01$], and extra-long ($M_s = .48$ and $.81$) [$t(29) = -6.36, p < .01$] deadline conditions. There were somewhat more false alarms to rearranged lures in the long deadline condition ($M = .46$) than in the extra-long deadline condition ($M = .39$) [$F(1,29) = 3.69, p < .07, \eta^2 = .11$] and for strong pairs ($M = .49$) than for weak pairs ($M = .36$) [$F(1,29) = 10.00, p < .01, \eta^2 = .26$]. However, the two-way interaction between deadline and strength failed to reach significance in the older group [$F(1,29) = .25, p = .63, \eta^2 = .01$]. Unlike young adults, older adults showed significant increases in false alarms with repetitions for rearranged pairs in both their shorter ($M_s = .40$ and $.51$) [$t(29) = -1.91, p < .04$ (one-tailed test)] and longer deadline conditions ($M_s = .32$ and $.46$) [$t(29) = -3.39, p < .01$].

Older participants had slightly, but not significantly, fewer false alarms to new pair lures in the long ($M = .15$) than in the extra-long deadline condition ($M = .17$) [$t(29) = -1.35, p = .19$]. Correcting the analyses for

hits and false alarms to rearranged lures by subtracting the new pair false alarm rates rendered the main effect of deadline for rearranged false alarms significant [$F(1,29) = 5.28, p < .03, \eta^2 = .15$], but as in the case of young adults, it could have no effect on the critical age $\times$ strength interactions. To summarize, older adults showed no benefit of increased response times in associative recognition performance. The drop in hit rates from the long to the extra-long deadline condition is difficult to explain, but we note that the mean study-test interval is greater for the extra-long deadline condition.

False alarms for rearranged and new lures. It is of interest to know whether with repetition, false alarm rates for rearranged lures returns to that of new lures for any condition. The evidence suggests that four repetitions are not sufficient for recollection to fully counter familiarity for any condition. False alarms to rearranged lures were more frequent than false alarms to new lures for all combinations of age, strength, and deadline (all $t_s \geq 2.78$, all $p_s \leq .01$). A $2 \times 2 \times 2$ (age $\times$ strength $\times$ deadline [shorter vs. longer for each age group]) ANOVA on rearranged lures yielded significant main effects of age, strength, and deadline. Older adults made more false alarms ($M = .42$) than did young adults ($M = .26$) [$F(1,54) = 11.79, p < .01, \eta^2 = .18$]. False alarm rates were also higher for strong pairs ($M = .39$) than for weak pairs ($M = .30$) [$F(1,54) = 12.94, p < .01, \eta^2 = .19$]. Furthermore, false alarm rates were higher for shorter deadlines ($M = .38$) than for longer deadlines ($M = .30$) [$F(1,54) = 13.91, p < .01, \eta^2 = .21$].

Discussion

The results comport well with dual-process models of memory. First, when young and older adults were tested at the same 4,500-msec deadline, an ironic effect of repetition (Jacoby, 1999) was observed for associative recognition. Young adults had a higher hit rate for repeated pairs with a concomitant drop in false alarms to rearranged lures, whereas older adults had both higher hit and false alarm rates for strong pairs. We interpret the observed decline in false alarms for young adults in this condition as pointing strongly to a role for recollective processing. Repetition had no effect on false alarm rates for rearranged lures in Kelley and Wixted (2001), suggesting a precise balance in the growth of familiarity and recollection with pair repetition at study. Kelley and Wixted argued that finding a drop in false alarms under these circumstances would support the ascendancy of recollection for strong pairs, which is what we observed here for young adults. Older adults, however, had higher false alarm rates for strong than for weak rearranged lures. Second, young participants showed a significant increase in false alarms to rearranged lures with repetition in the short deadline condition. Third, extending the time available to older adults for associative recognition did not lead to a decrease in false alarms to strong rearranged lures.

Our interpretation of these results is that both familiarity and recollection increase with repetition of word

pairs at study for young adults, but that recollection does not increase at the same rate as a function of presentation frequency for old and young adults. With a long response deadline, young adults successfully opposed the increased familiarity of rearranged lures with recollection of which words had not been studied together, although even for young adults false alarms to rearranged lures never were reduced to the baseline new lure rate. Because recollection has a slow rise-time, imposing a short deadline on young adults allowed familiarity to dominate, less checked by recollection. Older adults, on the other hand, had a significant increase in false alarms to rearranged lures in both the short and long deadline conditions. This suggests that, unlike young adults, older adults were less likely to recruit recollection to counter the adverse effect of familiarity when given more time to respond. These results are consistent with a relative decline in recollective processing in old age. Before elaborating on the theoretical implications of Experiment 1 and considering some alternative accounts of the data, we describe a followup experiment that rules out a relatively uninteresting alternative explanation of our findings.

EXPERIMENT 2

In Experiment 1, even with an extra-long deadline, older adults did not use recollection to counteract increased familiarity of the rearranged lures in the strong condition. Although this response deadline for older adults was quite long in Experiment 1 (5,500 msec), it is possible that it was not long enough to permit them to recruit recollective processes. Therefore, in Experiment 2, no response deadline was imposed, and responses were self-paced.

Method

Participants. Thirty-four young adults and 39 older adults participated in Experiment 2. The data from 3 young and 2 older participants were excluded from analysis due to experimenter error. Those from 4 older adults were excluded because they did not complete the main task. Thus, data from 31 young (13 men, 18 women) and 33 older (9 men, 24 women) adults, none of whom had participated in Experiment 1, were included in the analyses. Mean ages for the two groups were 19.42 ($SD = 1.93$, range = 18 to 26) and 71.55 ($SD = 6.17$, range = 60 to 80), for young and old, respectively. Additional information about the participants is given in Table 1.²

Materials. The words used in Experiment 1 were also used in Experiment 2. For practice, the participants studied 20 word pairs, 10 presented once (weak pairs), and 10 presented four times (strong pairs). Following study, the participants received a recognition test that consisted of 10 intact (5 weak, 5 strong), 10 rearranged (5 weak, 5 strong), and 10 new pairs. After the practice session, the participants studied two lists of 44 word pairs. Twenty of the pairs were presented once (weak pairs), 20 were presented four times (strong pairs), and 4 served as buffers (2 at each end of the list). After each study list, the participants received a recognition test that consisted of 20 intact pairs (10 weak, 10 strong), 20 rearranged pairs (10 weak, 10 strong), and 20 new pairs.

Procedure. The procedure in Experiment 2 was similar to that in Experiment 1, with the following changes. During the test, the participants were asked to decide whether each pair was *old* or *new* and then to rate their judgments on a 1–4 scale (*very uncertain* to *very*

certain). Responses were made orally and recorded by the experimenter. The participants were instructed to respond "old" only for test pairs that were identical to study pairs (intact pairs) and to respond "new" to all other pairs (rearranged pairs and new pairs). Unlike Experiment 1, responding was self-paced.

Results

As is evident in Figure 2, the results again demonstrated an ironic effect of repetition (Jacoby, 1999). Both young and older adults showed a significant increase in hits with repetition. Young adults had similar false alarm rates across repetitions. Older adults, however, had increased false alarms with repetition. Separate ANOVAs were carried out on hits, false alarms to rearranged pairs, and false alarms to new pairs. The ANOVAs confirm the visual impressions summarized above.

A 2×2 (age $\times$ strength) ANOVA conducted on hits to intact pairs yielded only a main effect of strength [$F(1,62) = 263.27, p < .01, \eta^2 = .81$]. Across age groups, there were more hits for strong pairs ($M = .92$) than for weak pairs ($M = .62$). For young adults, the mean hit rates for weak and strong pairs were .65 and .93, respectively. For older adults, these proportions were .59 and .91.

As in Experiment 1, false alarm rates for rearranged lures were higher than those for new lures for all combinations of age and strength (all t s ≥ 3.60 , all p s $< .01$.) A 2×2 (age $\times$ strength) ANOVA on the rearranged lures produced main effects of age [$F(1,62) = 9.53, p < .01, \eta^2 = .13$] and strength [$F(1,62) = 11.56, p < .01, \eta^2 = .16$]. Overall, older adults made more false alarms on rearranged lures ($M = .34$) than young adults ($M = .18$), and strong pairs were associated with higher false alarm rates ($M = .30$) than weak pairs ($M = .23$). These main ef-

fects must, however, be interpreted in light of the interaction between age and strength [$F(1,62) = 4.26, p < .05, \eta^2 = .06$]. For young adults, the results replicated Kelley and Wixted (2001), and Jones and Jacoby (2001)—young adults showed no significant increase in false alarms to rearranged lures when repetitions increased from one ($M = .17$) to four ($M = .19$) [$t(30) = -1.09, p = .28$]. Older adults, on the other hand, had significantly more false alarms to strong rearranged lures ($M = .40$) than to weak rearranged lures ($M = .29$) [$t(32) = -3.50, p < .01$], as would be expected if familiarity and recollection were differentially affected by age.

Finally, older adults made somewhat more false alarms to new pairs ($M = .08$) than young adults ($M = .04$) [$t(62) = -1.87, p < .07$]. Because of this marginally significant difference in base rates of responding "old" for older and young adults, the means for each of the other two pair types were corrected by subtracting out the new pair false alarm rate, and the analyses described above were repeated for the corrected data. Neither the main effect of strength or its interaction with age was affected by the baseline correction in either the analysis of hits or that of false alarms to rearranged lures. Nor was the main effect of age for rearranged false alarms affected by the correction. There was, however, a significant main effect of age group for hits [$F(1,62) = 4.18, p < .05, \eta^2 = .06$], that was not seen for the uncorrected data. Young adults had higher hit rates across study repetitions than older adults (M s = .75 and .67, respectively).

Discussion

The performance of young participants in Experiment 2 was similar to that of their Experiment 1 counterparts, with one exception. With repetition of word pairs at study, young adults' hits for intact pairs increased, whereas false alarms for rearranged lures remained unchanged. Thus, the outcome for rearranged lures replicated that of Kelley and Wixted (2001)—no difference in false alarm rates for strong and weak lures—rather than showing a drop with presentation, as in the long deadline condition of Experiment 1. We have no ready explanation for this discrepancy across studies, to which we return in the General Discussion section. The crucial point for our immediate purposes is that false alarms for rearranged lures did not show a significant increase with presentation frequency for young adults, whereas they did for older adults; even when older adults had unlimited time to respond, both hits and false alarms to rearranged lures significantly increased with repetition at study. These results again suggest that older adults were less successful in recruiting recollection to counteract increased familiarity due to repetition.

We note that even for young adults tested at the long deadline in Experiment 1 and without any deadline in Experiment 2, the false alarm rate for strong rearranged lures did not drop to the level of new pairs (see Cleary et al., 2001, for a similar result for word pairs in a frequency estimation paradigm and Seamon et al., 2002, for

Figure 2. Mean proportions of "old" responses (+SE) of young and older adults as a function of repetition in Experiment 2.

a related effect in the Deese/Roediger–McDermott task). It is possible that with additional repetitions, young adults' false alarms to strong rearranged lures would return to the new pair baseline and that older adults' rate of false alarms to strong rearranged lures would begin to diminish (cf. Budson et al., 2000, and Watson et al., 2004, for suggestions that endorsement of target lures by older adults in the Deese/Roediger–McDermott paradigm drops more slowly with study–list repetition in older than in young adults). Research examining the effects of presentation frequency over a larger range of repetitions is currently underway in our laboratory. The present results, however, suggest that heightened familiarity induced by repetition is not entirely counteracted by recollection.

GENERAL DISCUSSION

Our findings with respect to differences in the effects of pair strength in associative recognition across age, as well as effects of retrieval deadline on performance in young adults, can be easily accommodated by dual-process theories of memory that postulate roles for both familiarity and recollection. Repetition of word pairs at study led to improved associative recognition—defined as an increase in hit rates accompanied by either decreasing (Experiment 1) or stable (Experiment 2) false alarms to rearranged lures—only in young adults given adequate time to respond. A different outcome—increased hits to strong pairs accompanied by increased false alarms to rearranged lures—was observed for older adults. Moreover, limiting the time available for responding led to performance in young adults resembling that of older adults, but increasing response deadline did not lead to reduced acceptance of rearranged lures as studied items in older adults. Such results are not readily accommodated by simple single-process signal detection theories in which repetition increases the strength of representations of studied materials, and recognition decisions are based on strength or familiarity alone (Clark & Gronlund, 1996). Without invoking additional machinery, such as slowly recruited recollection or monitoring at retrieval to counter increased familiarity induced by repetition, the difference in outcome patterns across age and deadline conditions cannot be explained (e.g., Cleary et al., 2001; Hintzman & Curran, 1994; Jacoby, 1999; Jones & Jacoby, 2001; Kelley & Wixted, 2001). Similar conclusions have been reached for the Deese/Roediger–McDermott paradigm (e.g., Benjamin, 2001; Kensinger & Schacter, 1999; McDermott & Watson, 2001; Seamon et al., 2002; Watson et al., 2004).

More recent single-process models that assume independent representations of item and associative information in episodic memory (rather than separate familiarity and recollection processes) may also be able to handle our data (see, e.g., Gronlund & Ratcliff, 1989; McElree, Dolan, & Jacoby, 1999; Murdock, 1997).³ For instance, the pattern of results seen in Kelley and Wixted (2001) and for the young adults in our Experiment 2 can be pre-

dicted by assuming a two-step retrieval and decision process, with each step involving only a judgment of familiarity. In the first step, each pair is checked to determine whether both words are old or new, using a memory probe and decision process based solely on item information. Pairs judged to contain two old words are then passed on to a second stage in which a compound retrieval cue (association) is compared with information in episodic memory. Strong intact pairs produce better matches of the probe to episodic memory, so hit rates increase with repetition. However, strong rearranged lures should not produce higher false alarm rates than weak rearranged lures, because item information is irrelevant to second-stage decisions. On such a view, poorer associative recognition in older adults might result from reduced ability or willingness to base memory decisions on associative information, ignoring item information. Poorer performance in young adults under time pressure to respond could be due to the increased time and effort required to form associative than item cues or to slower search of episodic memory with associative than with item cues (e.g., Gronlund & Ratcliff, 1989; Murdock, 1997; Shiffrin & Steyvers, 1997). Whether such single-process global matching models can be successfully applied to all aspects of our data (e.g., the reduced false alarm rate for strong rearranged lures evidenced by young adults at their longer deadline in Experiment 1), or to associative recognition more generally, without invoking a recall or recollection process, is not clear at this time (e.g., Nobel & Shiffrin, 2001; see Malmberg, Holden, & Shiffrin, 2004, for models of recognition and frequency judgment in a plurality discrimination task). For the present, then, we frame our discussion in terms of dual-process familiarity/recollection models, while acknowledging alternative approaches that may prove fruitful.

The pattern of effects observed in Experiment 1 for young adults tested with a 4,500-msec deadline—strong pairs having a higher hit rate together with a lower false alarm rate and weak pairs having both a lower hit rate and higher false alarm rate—is an instance of the *mirror effect* (e.g., Glanzer, Adams, Iverson, & Kim, 1993), a phenomenon that has proven notoriously difficult for simple signal detection strength models to accommodate (see Clark & Gronlund, 1996, for a review). That is, if only strength or familiarity were operating, it is difficult to see why higher hit rates should not also be accompanied by higher false alarm rates. Some theorists have attempted to deal with mirror effects by invoking the notion of a criterion change, such that for strong items participants are certain enough that previously studied items are old that they can use a high criterion, thereby generating few false alarms, whereas when items are weak a lower criterion, yielding more false alarms, is needed to maintain desired hit rates. However, it has proven possible in some cases (e.g., when mirror effects are produced by varying word frequency) to influence hit rates without affecting false alarm rates (e.g., Arndt & Reder, 2002; Stretch & Wixted, 1998) or to influence remember

judgments (higher for rare words than for common words) without major consequences for know judgments (Joordens & Hockley, 2000). According to these theories, recollection is better for rare words than for common words (perhaps because these have fewer pre-existing associations to downgrade retrieval), but common words have higher baseline familiarity than rare words, accounting for the false alarm portion of the mirror effect. Balota, Burgess, Cortese, and Adams (2002) used dual-process logic in explaining changes in the mirror effect for word frequency across age. With increasing age, hit rates to high-frequency items remained constant, whereas hit rates to low-frequency items declined, presumably because of reduced recollection; for false alarms, there was no age $\times$ word frequency interaction, suggesting that these were the product of baseline familiarity.

In our associative recognition experiments, however, baseline familiarity cannot serve an explanatory role because all words were relatively infrequent in normative terms. Both intact and rearranged pairs also contained words that were experienced recently, so episodic familiarity of individual words was, at least nominally, the same. Moreover, in our experiments strength was manipulated within rather than across lists, and it is unclear how differential strength might be used as the basis for criterion shift under such conditions. Rather, it seems necessary to argue that both recollection and familiarity are involved in mirror effects in associative recognition brought about by increasing repetition frequency. Discriminating between intact and rearranged pairs clearly requires recollection of whether particular words were studied together (e.g., Clark & Gronlund, 1996; Hockley & Consoni, 1999; Kelley & Wixted, 2001; Rotello et al., 2000). Familiarity of word pairs bound during encoding could also contribute to accurate performance on old items (Nobel & Shiffrin, 2001; Yonelinas, 1997), but familiarity of individual words is not diagnostic. The simplest account is that recollection and familiarity (or associative and item information) act in consort to produce hits to intact items but must act in opposition if rearranged pairs, in which both items are familiar, are to be rejected. When response time is short, recollection is reduced, and the strong effects of repetition on familiarity emerge, as in the case of young adults in Experiment 1 tested at a short deadline. In older adults, recollection is differentially impaired (see Healy & Light, 2004, for supporting evidence from ROC analyses), and the mirror effect for strength is not seen—repetition increases both hits and false alarms to rearranged lures. The differing patterns of effects of repetition across age and deadlines are thus more readily encompassed by theories that incorporate processes that can act together or in opposition than by theories that postulate changes in response criteria.

The scenario described above is slightly complicated by one of the findings from Experiment 2. In that experiment, repetition increased hit rates without materially affecting false alarms to rearranged lures in young adults. This is the pattern observed by Kelley and Wixted (2001)

for associative recognition and by Jones and Jacoby (2001) for conjunction errors. It is also notable that studies of frequency judgment have produced quite mixed results in some paradigms bearing at least a surface resemblance to associative recognition, with judgments of zero frequency decreasing with repetition for intact items but sometimes increasing with repetition for lures similar to previously studied items and sometimes showing no discernable drop in false alarm rates to similar lures even after 25 repetitions (e.g., Cleary et al., 2001; Hintzman & Curran, 1995; Hintzman, Curran, & Oppy, 1992). The precise circumstances giving rise to one of these patterns rather than the other in associative recognition and frequency judgment are unknown, although both unquestionably require explanations in terms of more than simple strength or familiarity.

As indexed by an increase in false alarms to strong rearranged lures, older adults showed less benefit from more frequent study opportunities than did young adults. This result is consistent with the well-established finding that the trajectory for learning of paired associates over repeated study–test episodes is steeper in young than in older adults (e.g., Salthouse, 1994; see Kausler, 1994, for a review) in the more often encountered paradigm in which one member of each study pair is used to cue recall of its mate. The failure of older adults to benefit as much from repetition may have its basis in encoding (binding) problems, retrieval problems, or both. Naveh-Benjamin (2000), for instance, has interpreted greater age differences in associative than in item recognition as evidence for “reduced ability to encode and retrieve associations” (p. 1185) without further detailing the type of processes that might come into play at retrieval.

Binding problems would reduce the potential contribution of recollection—attempts to recall that intact pairs were studied together or that one member of a rearranged lure was studied with a different word cannot be successful if no association has been formed between members of a pair. There are, however, reasons to believe that binding deficits are not the only reason for the poorer performance of older adults in the present study. First, even in Experiment 2 where young and older adults were closely matched in hit rates, older adults made far more false alarms to rearranged lures, suggesting a difficulty in recollecting the original pairs to check for evidence of their association during study. Second, Dunlosky and Hertzog (1998) found similar levels of interactive imagery, sentence generation, repetition, or no strategy use when young and older adults were queried about encoding techniques after each word pair in a list was presented. Use of imagery and sentence generation were associated with higher cued recall of paired associates than repetition, but the effect was greater for young than older adults, indicating that use of the same strategy had different effects across age. It is possible that any mediators used by older adults in the present study were inferior in quality to those used by young adults. However, O’Kane, Wagner, and Corkin (2002) reported that young and

older adults did not differ in ratings of interactive images produced during study, but older adults nevertheless scored lower on associative recognition. Although we did not ask our participants in the present experiments to report how they studied particular pairs, Healy and Light (2004, Experiments 1 and 2) found that giving detailed instructions on forming and using associations boosted associative recognition for young, but not older, adults. Naveh-Benjamin (2000, Experiment 3) also obtained larger age deficits in memory for word–font pairings when participants were specifically asked to focus attention on encoding both elements of the stimulus rather than either word or font alone.

An alternative hypothesis is that there is no reduction of binding in old age, but rather an excess of binding (cf. Kroll et al., 1996). On this view, the members of pairs are not only associated together (bound) but also members of different pairs are associated with each other during encoding. Such indiscriminate binding would reduce the effectiveness of recollective processes because each word would, in effect, be associated with more than one other word. Increasing presentation frequency should, on this account, lead to both higher hit rates and higher frequencies of false alarms on rearranged pairs in persons suffering from a disinhibition of binding, because both correct and incorrect associations would be strengthened by repetition. This is precisely the pattern shown by older adults in the present experiments.

On the other hand, the fact that young adults had increased false alarms to strong rearranged lures in the short deadline condition of Experiment 1 argues forcefully for a retrieval, rather than an encoding, locus for this effect in this age group. It might thus be considered more parsimonious to attribute the effects of repetition in older adults in the present experiments to a deficit in recollection as well. Koutstaal (2003) reported that older adults can record perceptual details of pictures without subsequently making use of such information at test. In her study, pictures of objects (e.g., a seashell) were shown at study, and the recognition test included lures that were similar (e.g., a different seashell) to studied pictures, and new lures. When asked to respond “old” only to test items identical to studied items, older adults were more likely to falsely recognize similar lures, although hit rates did not differ across age. When asked to respond “old” to both previously studied and similar or conceptually related items, young and older adults did not differ in accuracy. On the latter test, and on a repetition priming test (size judgment), both age groups showed a benefit (higher hit rates and more priming) for pictures that were identical at study and test. Hence, encoding relevant information may facilitate responding when familiarity processes are engaged but may not lead to the use of recollection to check familiarity when correct responding requires discrimination between old items and similar lures.

One important but unanswered question is whether there are circumstances that would foster the use of rec-

ollective strategies to counter familiarity in older adults in associative recognition. There is evidence that older adults can use recollection to reject familiar test lures in other false-memory paradigms. For instance, on the encoding side, encouraging older adults to attend carefully to the perceptual characteristics of pictures reduces the likelihood of accepting categorically similar lures (e.g., other pictures of cats), although not to the same level as younger adults (Koutstaal, Schacter, Galluccio, & Stofer, 1999). Also, studying pictures can decrease false memory in the Deese/Roediger–McDermott task in both young and older adults (Schacter, Israel, & Racine, 1999), presumably by promoting a distinctiveness heuristic in which test items are compared with memories for studied items. A similar effect in the repeated lure paradigm has been reported by Dodson and Schacter (2002). On the retrieval side, older adults show reduced false memory for categorically related lures when required to make more specific source decisions (old and identical vs. new and related vs. new and unrelated) rather than simple old/new judgments (Koutstaal et al., 1999). Older adults also are less susceptible to both false fame and misleading information effects in an eyewitness suggestibility task when asked to make more specific source judgments at test (Multhaup, 1995; Multhaup, De Leonardis, & Johnson, 1999). Whether such phenomena will generalize to associative recognition remains a matter for future research.

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NOTES

1. Our review assumes a particular theoretical perspective. Alternative accounts of a number of these phenomena are available in terms of age-related deficits in binding information (e.g., Chalfonte & Johnson, 1996; MacKay & Burke, 1990), differential difficulty in storing item and associative information (e.g., Naveh-Benjamin, 2000; Naveh-Benjamin et al., 2003), or greater dependence on general rather than diagnostic contextual information (Mulligan & Hirshman, 1997). Moreover, we have assumed that contextual information plays a role chiefly in recollection rather than in familiarity. In global matching models, however, whether or not they include a recall-like or search process, it is familiarity that receives contributions from contextual matches between cues and information stored in memory (see Clark & Gronlund, 1996, for a review). It is unclear whether these alternative conceptions of aging or of memory processes can handle the range of age-sensitive and age-resistant memory effects that have been reported, or whether they make differential predictions about cognitive aging (see also Light et al., 2000). Investigations of memory and aging have used paradigms that lend themselves to ready interpretation within the dual-process familiarity/recollection framework. At the same time, global matching models of memory have been largely concerned with explanations of a set of regularities (e.g., list length effects, list strength effects, mirror effects, stability of slopes (or the lack thereof) of receiver operating characteristics [ROCs] in recognition) that have not been systematically explored across age. Consequently, there have been few attempts to apply global matching models to the aging of memory (see Bayen, Phelps, & Spaniol, 2000, and Malmberg, Zeelenberg, & Shiffrin, 2004, for some exceptions). An extensive treatment of this topic is not possible here, but we consider it briefly in the General Discussion section.
2. The Circling As task used in Experiment 1 was added in Experiment 2 after 5 young participants had been tested.
3. We are grateful to an anonymous reviewer for noting this alternative account.