Hyper-Binding Across Time: Age Differences in the Effect of Temporal Proximity on Paired-Associate Learning

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RESEARCH REPORT

Hyper-Binding Across Time: Age Differences in the Effect of Temporal Proximity on Paired-Associate Learning

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Older adults show hyper- (or excessive) binding effects for simultaneously and sequentially presented distraction. Here, we addressed the potential role of hyper-binding in paired-associate learning. Older and younger adults learned a list of word pairs and then received an associative recognition task in which rearranged pairs were formed from items that had originally occurred either close together or far apart in the study list. Across 3 experiments, older adults made more false alarms to near re-pairings than to far re-pairings. Younger adults, on the other hand, showed no difference in false alarms to the 2 types of rearranged pairs. These findings may be tied to the greater tendency of older adults to maintain access to recently attended information, inadvertently forming broader associations across time, than is the case for younger adults.

Keywords: aging, inhibition, binding, associative memory, paired-associate learning

A commonly held view within the field of cognitive aging is that older adults are less able than younger adults to form new associations (Chalfonte & Johnson, 1996; Naveh-Benjamin, 2000). This binding (or associative) deficit hypothesis is based on research using explicit tests of associative memory, as compared to tests of item memory (Old & Naveh-Benjamin, 2008; Spencer & Raz, 1995). However, recent work suggests that this deficit may be due, at least in part, to older adults' poorer regulation of attention resulting in a greater tendency to form irrelevant associations. So for example, older adults are more likely than younger adults to bind together target and distracting information that co-occurs in time (Campbell, Hasher, & Thomas, 2010), as well as irrelevant sequences of distractors that co-occur sequentially (Campbell, Zimerman, Healey, Lee, & Hasher, 2012). Here, we explore the possibility that this tendency toward excessive, or hyper, binding also plays a role in paired-associate learning and so contributes to older adults' typically higher rate of false alarms in associative recognition paradigms (e.g., Castel & Craik, 2003; Cohn, Emrich, & Moscovitch, 2008; Healy, Light, & Chung, 2005).

Consider a standard paired-associate learning task. Performance on this task requires participants to bind each of a series of (typically) unrelated pairs of items into a unit such that when a cue term occurs, the associated response can be produced. Retrieval success depends on the specificity of the association between each cue-response pairing, as the more responses that are bound to a single cue, the worse recall is for any one response (e.g., Anderson, 1974; Melton & Irwin, 1940; Postman & Underwood, 1973; Watkins & Watkins, 1975). Thus, optimal performance depends on one's ability to limit attention (and thus, obligatory binding processes; e.g., Logan & Etherton, 1994; Moscovitch, 1994) to the current word pair and to minimize intrusive thoughts or maintained representations from previous pairs so that they will not be inadvertently bound to that pair. These intrusive thoughts may include items that are semantically related to either word in the pair or items from a previous pair that have yet to be deleted from working memory. In fact, preventing associations across successive pairs may be particularly important when memory for the pairs is later tested using an associative recognition task, in which

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participants must distinguish intact pairs from those that have been rearranged. If associations were formed across pairs at study, some rearranged pairs (particularly those made up of nearby items) may seem old, resulting in a higher rate of false alarms than would be seen were cross-pair associations not formed during encoding.

Older adults, with their lessened ability to delete the recent past (Hasher, Zacks, & May, 1999), may be particularly prone to forming cross-pair associations. Although it is currently unknown whether older adults form irrelevant associations across temporal boundaries, there is recent evidence that older adults form more associations than younger adults in a number of circumstances (Campbell et al., 2010, 2012). An open question is whether there are also age differences in constraining memory binding over time so as to prevent unwanted associations between successive pairs in a standard paired-associate task. To address this question, we asked younger and older adults to learn a list of paired words and tested for false memory of cross-pair associations that might have been formed during learning. We used an associative recognition task that included intact and two types of rearranged pairs, those made up of items from successive pairs and those made up of items that occurred far apart in the list. If older adults inadvertently form associations across successive pairs at study, they should commit more false alarms to near-rearranged pairs than to far ones. Younger adults, on the other hand, should be more proficient at limiting their attention (and binding) to each successive pair in the list and, thus, should commit a similar number of false alarms to near- and far-rearranged pairs.

Experiment 1a

Method

Participants. Participants were 40 younger adults and 40 older adults. Younger adults were undergraduate students at the University of Toronto and received partial course credit or monetary compensation for their participation. Older adults were recruited from the community, and these adults received monetary compensation for their participation. Demographic information for all participants is shown in Table 1. Older adults had marginally more years of education, $t(78) = 1.89$, $p = .06$, and scored higher on the Shipley (1946) vocabulary test, $t(78) = 8.88$, $p < .001$, than younger adults, consistent with age related norms.

Participants from each age group were randomly assigned either to the near-rearranged condition or to the far-rearranged condition. Despite this random assignment, vocabulary scores differed significantly between the near and far groups, both in younger adults, $t(38) = 3.10$, $p < .01$, and in older adults, $t(38) = 2.06$, $p < .05$. Thus, we reran all analyses with vocabulary scores included as a covariate, but it did not change the pattern or significance of any results (therefore, we report the results without the covariate).

Materials. A total of 62 two-syllable concrete nouns (32 critical items and 30 fillers) were selected from the Toronto Word Pool (Friendly, Franklin, Hoffman, & Rubin, 1982), with the critical items randomly paired to form two sets of eight semantically unrelated pairs. Sets were matched on imagery, concreteness, and frequency in the language. The two sets were counterbalanced across participants such that each set either served as intact or rearranged pairs at test.

The study list consisted of 31 pairs: eight pairs that would serve as intact pairs on the test list, eight that would be rearranged, and 15 filler pairs (including three primacy and three recency buffer pairs). The test list consisted of the 16 critical pairs from study (eight intact, eight rearranged) presented in a random order. All rearranged pairs were made from forward-going pairs in the study list (i.e., the cue term from pair n was repaired with the response term from pair $n + 1$, in the case of near re-pairings, or $n + 9$, in the case of far re-pairings). This was done because previous work suggests that cue words serve as a conceptual peg onto which response terms are bound (Lambert & Paivio, 1956; Paivio, 1991), and thus, if participants were to form associa-

Table 1
Demographic Information for Experiments 1a, 1b, and 2

Group	Age (years) *M*	Age (years) Range	Age (years) *SD*	Education (years) *M*	Education (years) *SD*	Vocabulary score *M*	Vocabulary score *SD*
Experiment 1a							
Younger							
Near ($n = 20$)	20.25	17–26	0.51	14.60	0.50	32.04	0.61
Far ($n = 20$)	20.25	18–25	0.53	14.35	0.45	29.30	0.63
Older							
Near ($n = 20$)	70.60	63–77	0.98	14.75	0.68	35.74	0.80
Far ($n = 20$)	68.50	63–77	0.93	16.45	0.68	37.60	0.44
Experiment 1b							
Older							
Near ($n = 18$)	68.17	63–76	0.87	18.17	0.62	36.21	0.98
Far ($n = 18$)	69.56	61–77	1.05	15.94	0.83	36.10	0.66
Experiment 2							
Younger							
($n = 20$)	19.50	18–27	2.86	13.03	2.04	30.03	7.68
Older							
($n = 20$)	65.90	60–77	4.40	16.58	2.79	37.25	1.70

Note. Vocabulary scores are from the Shipley (1946) test. Vocabulary information was missing for two participants.

tions across pairs, we expected this effect to be largest for forward-going associations.

Ordering of the study list was constrained by the need to have near and far pairs, as well as intact pairs, evenly spaced throughout the list. Once these slots were determined, word pairs were randomly assigned to position.

Procedure. Before the study phase, participants were told that they would see a list of word pairs and were instructed to form an association between each pair of words, so as to be able to distinguish intact pairs from rearranged pairs at test. No mention was made of the near/far manipulation. Participants were then given a practice trial with four unique word pairs, and the experimenter discussed any errors.

During the study phase, each pair was presented for 2,000 ms, followed by a 500 ms interstimulus interval (ISI). After the study phase, participants were asked to count backward by threes from a set number for 90 s. This was immediately followed by the associative recognition test. Test pairs were shown one at a time, in a different random order for each participant. The test phase was self-paced, with participants making a yes/no key-press response to indicate whether or not each pair had been seen at study.

Results and Discussion

In this and the following experiments, the term "hits" refers to intact pairs that were correctly endorsed as old, while the term "false alarms" refers to rearranged pairs that were incorrectly endorsed as old. Proportions of hits, false alarms, and corrected recognition (proportion of hits minus proportion of false alarms) are shown in Table 2. As we were primarily interested in group differences in the rate of false alarms, we first submitted the false alarm data to an analysis of variance (ANOVA) with age (young, old) and rearranged pair-type (near, far) as between-subjects factors. The main effects of age, $F(1, 76) = 5.61$, $p < .05$, $MSE = 0.18$, partial $\eta^2 = .07$, and rearranged pair-type, $F(1, 76) = 13.18$, $p < .05$, $MSE = 0.41$, partial $\eta^2 = .15$, were both significant. Furthermore, these effects were qualified by a significant interaction between age and rearranged pair-type, $F(1, 76) = 9.97$, $p < .05$, $MSE = 0.31$, partial $\eta^2 = .12$. As shown in Figure 1, older adults in the near-rearranged group made more false alarms than those in the far-rearranged group, $t(38) = 4.78$, $p < .001$. In contrast, younger adults' false alarm rates were unaffected by the near/far manipulation ($t < 1$).

In contrast to the false alarm data, hit rate was relatively similar across groups (see Table 2). To confirm this impression, hits were also submitted to a 2 (age) × 2 (rearranged pair-type) ANOVA. Reflecting the stability of hit rate across conditions, none of the effects was significant: age, $F(1, 76) = 1.78$, $p = .19$; rearranged pair-type ($F < 1$); and Age × Rearranged Pair-Type ($F < 1$). Thus, older adults' higher false alarm rate in the near-rearranged condition was not accompanied by a lessened ability to endorse intact pairs as old.

Finally, we also submitted corrected recognition to a 2 (age) by 2 (rearranged pair-type) ANOVA. The main effects of age, $F(1, 76) = 5.06$, $p < .05$, $MSE = 0.47$, partial $\eta^2 = .06$, and rearranged pair-type, $F(1, 76) = 5.48$, $p < .05$, $MSE = 0.51$, partial $\eta^2 = .07$, were both significant, as was the interaction between these factors, $F(1, 76) = 4.66$, $p < .05$, $MSE = 0.43$, partial $\eta^2 = .06$. Planned contrasts revealed that while there was no age difference when rearranged pairs came from far apart in the study list, $t(38) = 0.06$, $p = .95$, older adults showed poorer corrected recognition than younger adults when rearranged pairs came from close together in the study list, $t(38) = 3.59$, $p < .01$.

Table 2
Mean Proportion of Hits, False Alarms, and Corrected Recognition in Experiments 1a and 1b

Group	Hits	False alarms	Corrected recognition
Experiment 1a			
Younger			
Near	.77 (.03)	.19 (.04)	.58 (.06)
Far	.76 (.05)	.18 (.04)	.59 (.08)
Older			
Near	.69 (.04)	.41 (.04)	.28 (.06)
Far	.73 (.05)	.14 (.04)	.58 (.07)
Experiment 1b			
Older			
Near	.83 (.03)	.40 (.06)	.42 (.06)
Far	.77 (.04)	.25 (.05)	.52 (.07)

Note. Corrected recognition = proportion of hits − proportion of false alarms. Values in parentheses are standard errors of the mean.

Experiment 1b

The study rate used in Experiment 1a was exceptionally fast (2 s/pair), and this may have contributed to the particularly poor performance of older adults in the near-rearranged condition. Here, we sought to replicate the critical near-far difference by testing a new group of older adults at a slower study rate (4 s/pair).[1] On the assumption that the underlying mechanism responsible for the near-far effect is the inadvertent formation of cross-pair associations, we once again expected older adults in the near-rearranged group to make more false alarms than those in the far-rearranged group.

Method

Participants. Thirty-six older adults from the community volunteered to participate and received monetary compensation for their participation. Participants were randomly assigned to either the near- or far-rearranged condition. Despite random assignment, participants in the near condition had more years of education than those in the far condition, $t(34) = 2.14$, $p < .05$. Education was included as a covariate in all analyses but did not change the pattern or significance of any results (therefore, we report the results without the covariate).

Materials and procedure. The materials and procedure were identical to those used in Experiment 1a. The only exception was the slower presentation rate used at study, with each word pair shown for 4,000 ms (500 ms ISI).

Results and Discussion

Proportions of hits, false alarms, and corrected recognition are shown in Table 2. As can be seen, we replicated the effect of

[1] Twelve younger adults piloted at this slower study rate were at ceiling (i.e., made almost no false alarms).

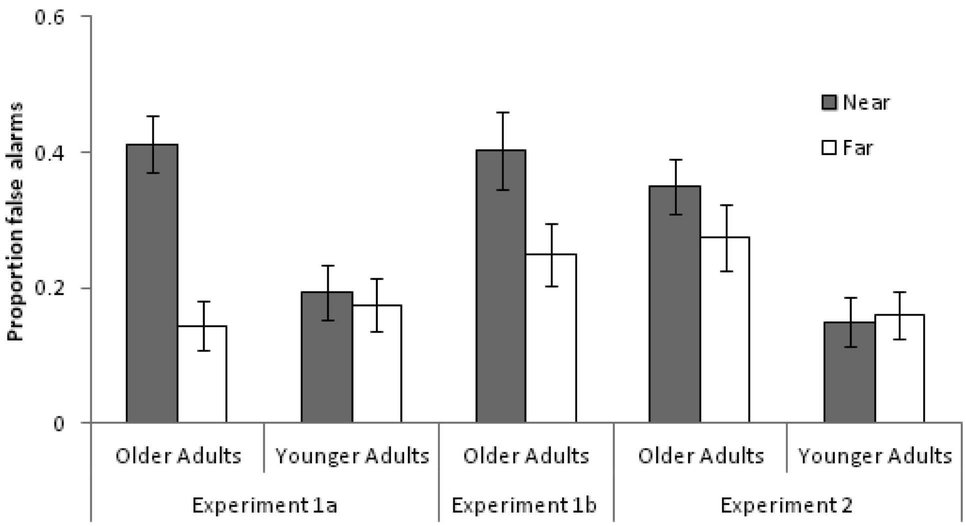

Figure 1. Mean false alarm rate by age group and rearranged pair-type condition in Experiments 1a, 1b, and 2. Error bars represent standard errors of the means.

pair-type (see Figure 1), in that older adults in the near-rearranged group once again made more false alarms than those in the far-rearranged group, $t(34) = 2.11$, $p < .05$, but they did not differ in terms of hits, $t(34) = 1.05$, $p = .30$. Thus, even at this slower study rate, the near-rearranged pairs were more likely to be called old than the far-rearranged pairs. We note that older adults' overall rate of false alarms did not improve at this slower study rate ($M = 0.33$, $SD = 0.23$) relative to that in Experiment 1a ($M = 0.28$, $SD = 0.22$), $F(1, 72) = 1.13$, $p = .29$. However, the average hit rate did increase from .71 ($SD = 0.21$) in Experiment 1a to .80 ($SD = 0.16$) in this experiment, $F(1, 72) = 4.46$, $p < .05$, demonstrating that more study time resulted in higher endorsement of intact pairs. Despite better overall performance, older adults still made more false alarms to near re-pairings than to far ones.

Experiment 2

In Experiment 1, the near-far manipulation was between subjects. In this experiment, we sought to replicate the critical age by pair-type interaction using a within-subjects design.

Method

Participants. Participants were 20 younger and 20 older adults drawn from the same pools as in Experiment 1. Demographic information is presented in Table 1. Older adults had more years of education, $t(38) = 4.59$, $p < .001$, and scored higher on the vocabulary test, $t(38) = 7.88$, $p < .001$, than younger adults.

Materials and procedure. The procedure was identical to that used in Experiment 1a, except that we increased the delay between study and test to 2 min and included two study-test trials with a 10-min nonverbal filler task between the two. Splitting the procedure into two study-test trials allowed us to test whether the critical effect would hold for more pairs.

A total of 156 two-syllable concrete nouns (80 critical items and 76 fillers) were selected from the Toronto Word Pool (Friendly et al., 1982), with the critical items randomly paired to form four sets of 10 semantically unrelated pairs. Sets were matched on imagery, concreteness, and frequency in the language. The four sets were counterbalanced across participants such that each set served equally often as either intact or rearranged pairs on either the first or second test trial.

On each of two study trials, participants saw 39 pairs, 10 pairs that would serve as intact pairs on the test list, 10 that would be rearranged (five near and five far), and 19 filler pairs (including three primacy and three recency buffer pairs). Near-rearranged pairs appeared sequentially, and far-rearranged pairs appeared at a lag of seven pairs within the study list. Near, far, and intact pairs were evenly spaced throughout the list and once these slots were determined, word pairs were randomly assigned to position. Each test list consisted of the 20 critical pairs from study (10 intact, five near-rearranged, and five far-rearranged) presented in a different random order for each participant.

Results and Discussion

Data were collapsed across trials and false alarms were submitted to an ANOVA with age (young, old) as a between-subjects factor and rearranged pair-type (near, far) as a within-subjects factor. There was a significant main effect of age, $F(1, 38) = 8.78$, $p < .01$, $MSE = 0.50$, partial $\eta^2 = .19$, but not rearranged pair-type, $F(1, 38) = 2.53$, $p = .12$ (means and standard errors shown in Table 3). The critical interaction between age and rearranged pair-type was significant, $F(1, 38) = 4.32$, $p < .05$, $MSE = 0.04$, partial $\eta^2 = .10$. As shown in Figure 1, older adults once again made more false alarms to near re-pairings than to far re-pairings, $t(19) = 3.13$, $p < .01$, while younger adults' rate of false alarms was unaffected by pair-type, $t < 1$. Furthermore, as shown in Table 3, hit rate did not differ between the two groups, $t < 1$, but younger adults had higher corrected recognition than older adults, $t(38) = 2.27$, $p < .05$.

Table 3
Mean Proportion of Hits, False Alarms, and Corrected Recognition in Experiment 2

Age group	Hits	Near false alarms	Far false alarms	Total false alarms	Corrected recognition
Younger	.79 (.03)	.15 (.04)	.16 (.04)	.16 (.03)	.64 (.05)
Older	.77 (.03)	.35 (.04)	.28 (.05)	.31 (.04)	.46 (.06)

Note. Means are collapsed across test Trials 1 and 2. Corrected recognition = proportion of hits − proportion of total false alarms. Values in parentheses are standard errors of the mean.

General Discussion

In these studies, older and younger adults performed an associative recognition task in which rearranged pairs came from either close together or far apart in the study list. Older adults consistently made more false alarms to near re-pairings than to far re-pairings, suggesting that rearranged pairs from close together in the study list were more likely to seem old to older adults. In contrast, younger adults' rate of false alarms was unaffected by temporal proximity within the study list, an effect that replicates previous work within that age group (e.g., Hannigan & Reinitz, 2000; Reinitz & Hannigan, 2001). Hit rate, on the other hand, did not vary across age group or re-pairing condition, suggesting that (a) older adults are just as good as younger adults at endorsing intact pairs as old, which is in line with previous work (e.g., Castel & Craik, 2003; Cohn et al., 2008) and (b) our near/far manipulation did not affect participants' ability to identify previously viewed pairs.

Why did the false alarm rate vary with the nature of the repaired items? We attribute this to the ability to focus only on learning the immediately presented pair without input from previous pairs—input that may be the result of a failure to suppress no longer relevant items. Several experimental tasks require the deletion of previously attended information in order to minimize the build-up of proactive interference, and maximize performance, as one proceeds through the task. For instance, complex span tasks and classic studies of serial recall that use multiple study-test trials both require restriction of recall to the current memory trial (e.g., Conrad, 1960; May, Hasher, & Kane, 1999); *n*-back tasks require the rejection of repeated stimuli that appeared close to, but not exactly, *n* trials ago (e.g., Kane, Conway, Miura, & Colflesh, 2007); and directed forgetting experiments intentionally instruct participants to delete previously learned information (Bjork, Bjork, & Anderson, 1998). It has been argued that inhibition is needed to suppress previously, but no longer, relevant items from working memory so as to minimize interference within these tasks (Friedman & Miyake, 2004; Hasher et al., 1999; Kane, Conway, Hambrick, & Engle, 2007). Furthermore, numerous studies suggest that the ability to delete previously attended information shows a marked decline with age, as older adults' performance on these tasks is greatly improved by conditions that minimize the build-up of proactive interference (e.g., Lustig, May, & Hasher, 2001; May et al., 1999; Rowe, Hasher, & Turcotte, 2008, 2010; Sahakyan, Delaney, & Goodmon, 2008).

Here, we make the unique suggestion that a similar sort of attentional restriction over time is needed in order to succeed at paired-associate learning. That is, learning a list of word pairs requires one to limit attention, and therefore obligatory binding processes (e.g., Logan & Etherton, 1994; Moscovitch, 1994), to each individual pair. If one's mind wanders to a related thought, or continues to dwell on a previous pair, then these now-irrelevant concepts are likely to be bound, however loosely, to the current target pair. At retrieval, any erroneously encoded associations may again come to mind in response to a given cue and ultimately interfere with retrieval of the target response (e.g., Anderson, 1974; Watkins & Watkins, 1975). Here we show that older adults, with their lessened ability to dampen down extraneous thoughts (e.g., Hamm & Hasher, 1992), may be more susceptible to the formation of irrelevant associations, including those formed across successive pairs within a paired-associate list. Furthermore, in so far as older adults may be used as a test case for lessened inhibitory control, these results make the more general point that paired-associate performance is contingent on individual differences in attentional control.

The test list in most associative recognition studies is likely to be a mix of near and far re-pairings, and it is possible, though of course unknown, that older adults' typically higher rate of false alarms (e.g., Castel & Craik, 2003; Cohn et al., 2008; Healy et al., 2005) is partly due to the presence of near-repaired items in the test list. Indeed, this study used only very near and very far re-pairings, and it is unclear what the performance relationship would be to a range of distances. However, a glimpse of this relationship may be obtained by comparing age differences in false alarm rates to far re-pairings across Experiments 1 and 2, as the far re-pairings in Experiment 1 were at a longer lag (nine items) than were those in Experiment 2 (seven items). In Experiment 1a, older and younger adults did not differ in their false alarms to these nine-lag pairs, $t(38) = 0.59$, $p = .28$, and the same finding held when comparing older adults from Experiment 1b to the young from Experiment 1a, $t(36) = 1.25$, $p = .22$. In Experiment 2, however, older adults made more false alarms to these seven-lag re-pairings than younger adults, $t(38) = 1.93$, $p < .05$. Thus, even repaired items that were several lags apart at study seemed more familiar to older adults, although not as familiar as those that were even closer together (i.e., in adjacent pairs, or lag 1).

Within a standard associative recognition paradigm, rearranged pairs are presumably randomly distributed throughout the study list, but it may be the inclusion of relatively close re-pairings (at a lag of seven or less) that drives up older adults' overall rate of false alarms. Moreover, in so far as the entire study list represents a single event, the constituent parts of which may be bound together, older adults may be more susceptible to the formation of remote associations across distant items within the study list (Ebbinghaus, 1885/1964; but see Slamecka, 1985). From this view, all repaired items should seem more familiar to older than younger adults, which may contribute to their heightened rate of false alarms. Nonetheless, as a demonstration of the power of associative binding in older adults (or hyper-binding across time), these findings suggest yet another way in which age differences in associative memory performance may actually be caused by the formation of too many associations, rather than too few (Campbell et al., 2010; but see Chalfonte & Johnson, 1996; Naveh-Benjamin, 2000).

At a more general level, the present results suggest that as older adults, and others with compromised inhibitory control (e.g., Luck & Gold, 2008; Nigg, 2000), move through the world, they may be more likely than healthy younger adults to blur the boundaries between successive events (Ezzyat & Davachi, 2011; Zacks, Speer, Swallow, Braver, & Reynolds, 2007). Indeed, when asked to segment a narrative into distinct events, older adults produce longer event units and show less consensus about event boundaries than younger adults (Zacks, Speer, Vettel, & Jacoby, 2006). Within a laboratory setting, this temporal blurring may lead older adults to treat the entire experimental session as one large event, rather than a series of separate tasks, as younger adults seem to do (e.g., Oliphant, 1983; Radvansky, Krawietz, & Tamplin, 2011).

The failure to down-regulate accounts for older adults' greater access to information that is no longer relevant as they move from one task to the next, as occurs even when participants are not alerted to a connection between the tasks (e.g., Rowe, Valderrama, Hasher, & Lenartowicz, 2006; Thomas & Hasher, 2012). The failure to down-regulate may also explain why context changes more slowly for older than younger adults (Balota, Duchek, & Paullin, 1989; but see Howard, Kahana, & Wingfield, 2006; Kahana, Howard, Zaromb, & Wingfield, 2002), as recently encountered representations remain active for longer and become integrated with the present moment. In fact, what constitutes the present moment or "the now" may, as a result, be broader for older adults.

In the real world, this broader sense of "the now" or the tendency to form associations across event boundaries may contribute to older adults' poorer memory for event details and greater recall of the gist (e.g., Castel, Farb, & Craik, 2007; Craik, 2002; Holland & Rabbitt, 1990; Levine, Svoboda, Hay, Winocur, & Moscovitch, 2002). While loss of detail is generally thought to be indicative of memory failure, older adults may be better poised to see the "big picture," as their linking together of ideas may be less constrained by temporal proximity.

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