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Effects of Aging, Distraction, and Response Pressure on the Binding of Actors and Actions

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Two experiments provide evidence for an age-related deficit in the binding of actors with actions that is distinct from binding deficits associated with distraction or response pressure. Young and older adults viewed a series of actors performing different actions. Participants returned 1 week later for a recognition test. Older adults were more likely than young adults to falsely recognize novel conjunctions of familiar actors and actions. This age-related binding deficit occurred even when older adults could discriminate old items from new items just as well as could young adults. Young adults who experienced distraction or time pressure also had difficulty discriminating old items from conjunction items, but this deficit was accompanied by a deficit at discriminating old and new items. These results suggest that distraction and response pressure lead to deficits in memory for stimulus components, with any deficits in binding ability commensurate with these deficits in component memory. Aging, in turn, may lead to binding difficulties that are independent of attention-demanding executive processes involved in maintaining individual stimulus components in working memory, likely reflecting declines in hippocampally mediated associative processes.

Keywords: event memory, binding, associative deficit, conjunction memory error, hippocampus

Binding information in memory is crucial to accurately remembering an event. For example, an eyewitness to a crime must remember not only the people who were present and the actions that were performed but also which people were associated with which actions. Naveh-Benjamin (2000) proposed that older adults have a deficit at binding information in memory, and Kersten, Earles, Curtayne, and Lane (2008) showed that older adults perform more poorly than young adults at remembering which people performed which actions. It is difficult, however, to clearly demonstrate that age differences in memory for who did what stem from a binding deficit rather than from deficits in remembering the basic components of an event (the who or the what).

One strategy for characterizing the effects of aging on different aspects of the memory system is to compare these effects to effects of environmental variables such as distraction and response pressure. For example, Craik (1983) proposed that aging involves a decline in attentional resources and thus that memory performance in older adults can be simulated in young adults by imposition of distraction. The memory performance of young adults who are distracted while encoding stimuli indeed sometimes resembles that of older adults (Anderson et al., 2000). In contrast, young adults who are distracted during retrieval often show no memory deficit (Naveh-Benjamin, Craik, Guez, & Kreuger, 2005). These results suggest that memory deficits associated with aging and distraction stem from insufficient attentional resources at encoding.

Research on binding in memory, however, has revealed differences between the effects of aging and distraction. For example, Naveh-Benjamin and colleagues (Kilb & Naveh-Benjamin, 2007; Naveh-Benjamin, Guez, Kilb, & Reedy, 2004; Naveh-Benjamin, Guez, & Marom, 2003) presented distracted and nondistracted young and older adults with lists of paired stimuli, such as word pairs and name–face pairings, and later tested them on memory for either the individual components of those stimuli or the pairings of components. Older adults performed more poorly than nondistracted young adults at discriminating novel from familiar pairings of familiar components, even when older adults matched young adults at recognizing those components in isolation. In contrast, distracted young adults exhibited a more general deficit, showing similar impairments on tests of memory for individual components and their pairings. Kilb and Naveh-Benjamin explained these results by proposing that aging impacts the ability to form new associations in memory and that this impairment is distinct from impairments associated with reductions in attentional resources.

Jones and Jacoby (2005) also compared the effects of age to those of an environmental manipulation, response pressure, on memory for component stimuli and their pairings. They tested participants' recognition memory for compound words (e.g., *blackmail*, *jailbird*). Recognition lures included not only entirely new words but also words that involved one or more familiar

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components in novel combinations (e.g., *blackbird*). Discriminating these conjunction items from old items thus required that participants remember the stimulus components and how they were paired.

The performance of young adults was examined under varying degrees of response pressure. In the short-deadline condition, participants had to respond to recognition items within 850 ms. In the long-deadline condition, participants waited 1,400 ms before an 850-ms response window opened. Older adults all had a long deadline. Both young adults with response pressure and older adults without response pressure could thus be compared with young adults without response pressure.

All three groups falsely recognized conjunction items more often than new items. This result suggests that participants received a feeling of familiarity for the components without recollecting how those components were paired during encoding. It is important to note that these effects of component familiarity were nearly identical for young adults with response pressure and older adults without response pressure. Effects of component familiarity were smaller in young adults without response pressure, suggesting that these young adults could use recollection of the context in which a component appeared at encoding to reject that same component in a new context. This smaller effect of component familiarity in this group than in either older adults or time-pressured young adults suggests that aging and time pressure similarly impacted use of recollection to reject the conjunction items.

Two different lines of research thus suggest different conclusions regarding the extent to which the effects of aging on the binding of stimulus components can be mimicked in young adults through environmental manipulations. A possible explanation stems from the different materials that were used. In the research of Naveh-Benjamin and colleagues, each item in a pair retained its separate identity and meaning regardless of how it was paired. Thus, when young adults were tested with a stimulus pair, they could use one item in a pair to help them retrieve the other item that was paired with it at encoding. If the other item that they retrieved did not match the current item, young adults could confidently reject the test pair. Older adults may have had greater difficulty using this retrieval strategy, making them more likely to incorrectly accept novel recombinations of familiar items.

In contrast, the compound words employed by Jones and Jacoby (2005) were composed of word fragments that did not always retain the same meaning when recombined with other word fragments. For example, the meaning of *bird* in *jailbird* is quite different from its meaning in *blackbird*. Thus, even young adults in the absence of distraction or response pressure may have difficulty using the fragment *bird* in *blackbird* to recollect the previous compound word in which *bird* had appeared.

Perhaps for this reason, Jones and Jacoby (2005) were only able to demonstrate the use of recollection to reject conjunction items when those items were composed of fragments that had been presented visually three times each, and participants were instructed to accept only compound words that had been presented orally. It is not clear, however, that retrieving a visual representation of a printed word fragment—thus inferring that it could not have been presented orally—involves associative information to the same extent as does using a cue word to retrieve the other word with which it had been originally paired.

The different conclusions regarding whether age effects can be mimicked by distraction and response pressure could thus reflect the extent to which the materials used by Kilb and Naveh-Benjamin (2007) and Jones and Jacoby (2005) promote the use of associative memory. An interesting test case for this conjecture is provided by stimuli developed by Kersten et al. (2008; Earles, Kersten, Curtayne, & Perle, 2008). Kersten et al. tested young and older adults on their recognition memory for events involving different female actors performing different actions, such as waving a flag or peeling a banana. The critical test items involved familiar actors performing familiar actions that had been performed by somebody else. Rejecting these conjunction items thus required participants to remember which actor performed which action.

In three experiments, older adults were more likely than young adults to falsely recognize novel conjunctions of familiar actors and actions. This result was obtained even when memory for the individual components of a stimulus was equated in the two groups. Thus, older adults remembered the actors and actions just as well as did young adults but had difficulty remembering which actor performed which action.

The stimuli of Kersten et al. (2008) represent an interesting test case for the theory of an age-related associative deficit because they are a combination of some of the characteristics of the stimuli of Kilb and Naveh-Benjamin (2007) with some of the characteristics of the stimuli of Jones and Jacoby (2005). Similar to the compound word stimuli of Jones and Jacoby, the actor and action in an event form a cohesive unit. The action being performed depends upon the actor's body for expression, and the actor only appears in the context of performing that action. The same action may thus appear somewhat different when performed by different people, just as a word fragment can carry different meanings in different compound words.

Despite the conjoint nature of an actor–action pairing, the actor and action in an event may also retain their separate identities, similar to the individual words in the word pairs employed by Kilb and Naveh-Benjamin (2007). In particular, brain regions such as the fusiform gyrus respond to the identity of an individual independently of the actions that the individual is performing (Haxby, Hoffman, & Gobbini, 2000). Furthermore, a mirror neuron system maps actions performed by another person onto one's own actions, such that the same actions performed by different individuals are all represented in terms of one's own motor system (Rizzolatti & Craighero, 2004). Thus, even though an actor and action may always be presented in combination, they may be encoded in terms of separate representations.

Remembering which actor performed an action may thus require one to associate independent representations of that actor and action. These associations would allow one to use the actor in an event to retrieve other actions one has seen that actor perform. This in turn would provide one with a basis for rejecting a novel conjunction of a familiar actor and action, because one could use the actor in a conjunction item as a cue to retrieve that same actor performing a different action at encoding.

If one can indeed use associations between actors and actions to rule out a novel conjunction of a familiar actor and action, then the associative deficit hypothesis predicts that young adults should be better at using these associations than are older adults, leading to a higher rate of false recognition of conjunction items in older adults than in young adults. Furthermore, if aging has a disproportionate impact on binding ability, then distraction and response pressure may not fully mimic the effects of age on the binding of actors and actions. In particular, distraction and response pressure may lead to deficits in the binding of actors and actions that are commensurate with deficits in memory for those individual components, whereas aging may lead to binding deficits above and beyond any deficits in component memory.

Experiment 1

In Experiment 1, we compared the effects of age and distraction on the binding of actors and actions. Young and older adults viewed 30 different actors each performing a different action. Participants returned 1 week later for a recognition test. The older adults and one group of young adults completed both the encoding and retrieval sessions without distraction. Other young adults engaged in a distractor task during encoding to test whether distracted young adults resemble nondistracted older adults in their encoding of relations between actors and actions. A third group of young adults was distracted at retrieval to test whether distracted young adults resemble nondistracted older adults in their retrieval of associations between actors and actions.

Method

Participants. Forty-eight undergraduates (*M* age = 19.51 years, *SD* = 2.31 years) participated for course credit. Sixteen older adults (*M* age = 67.68 years, *SD* = 6.75 years) from lifelong learning classes received $20 gift certificates. Participant characteristics are given in Table 1.

Stimuli. We used 210 video clips from Kersten et al. (2008), each showing a female actor performing a simple action. Each participant saw one of four encoding lists of 30 different actors, each performing a different action. Four retrieval lists of 150 video clips corresponded to the four encoding lists. Thirty old items were identical to encoding items. In 30 conjunction items, an actor seen at encoding performed an action that had been performed by a different actor at encoding. In 60 new component items, a familiar actor (or action) was paired with a new action (or actor). Finally, in 30 new items, a new actor performed a new action.

Table 1
Participant Characteristics in Experiment 1

	Young adults		Older adults		
Variable	*M*	*SD*	*M*	*SD*	*p*
Age	19.51	2.31	67.68	6.75	<.001
Education	12.35	0.67	16.63	2.78	<.001
Health	4.03	0.75	4.13	0.62	.65
Medications	0.48	0.83	3.69	2.12	<.001
Vocabulary	27.23	3.09	36.25	1.88	<.001

Note. Symbol *p* = probability level associated with the comparison between young and older participants; Education = number of years of education; Health = self-reported health on a scale of 1 (*poor*) to 5 (*excellent*); Medications = number of prescription medications currently being taken; Vocabulary = score out of 40 on the Shipley (1986) Vocabulary Test.

In addition, 153 distractor sentences each described a simple scenario unrelated to the video clips (e.g., "The girl went to the party in a taxi."). A multiple-choice question (e.g., "Where did the girl go?") was also created for each sentence with three response alternatives.

Procedure. Participants watched 30 encoding video clips in a unique random order for each participant. Participants were instructed that they would be tested on their memory of the actions and the identity of the actor for each one. For the distraction at encoding condition, each video was accompanied by a distractor sentence presented orally by the experimenter. After the video ended, these participants clicked on one of three possible answers to a multiple-choice question, whereas other participants clicked on "Next event." Distracted participants received three practice sentence and question trials before viewing the first video clip. After viewing the video clips, participants completed a demographics questionnaire and vocabulary test (Shipley, 1986).

Participants returned 1 week later for a recognition test. They were instructed that they were to judge whether they had seen each video clip earlier and rate how confident they were in their judgment. Participants were warned that some video clips involved an actor and action seen earlier but that this actor had not previously performed this action. Participants were instructed to respond "no" to these video clips. The distraction at retrieval condition received three practice trials before the first test item.

Participants watched 150 retrieval video clips in a unique random order for each participant. For the distraction at retrieval condition, each video clip was accompanied by an orally presented distractor sentence. After each video clip, participants were asked, "Did you see this person perform this action in the first part of the experiment?" Participants then rated their confidence, selecting from buttons labeled "Just guessing," "Pretty sure," and "Absolutely sure." Distracted participants then answered a question relating to the distracter sentence.

Results

Participants' performance at answering questions regarding the distractor sentences was slightly but significantly better in the distraction at encoding condition (*M* = 99.4%, *SD* = 0.34%) than in the distraction at retrieval condition (*M* = 98.4%, *SD* = .30%), $t(30) = 2.12$, $p < .05$. This result is consistent with those of prior studies showing a larger impact from retrieval than from encoding on secondary task performance (e.g., Fernandes & Moscovitch, 2000).

Proportions of "yes" responses to the different item types are in Table 2. In order to derive measures of recognition sensitivity, we combined participants' yes/no recognition judgments with their confidence ratings (indicated on a 3-point scale) to provide a 6-point measure of confidence that a given item had been seen before. Each group's average rate of acceptance of a given item type at each level of confidence was computed. We then computed receiver operating characteristics (ROC) functions for each group, relating acceptance rates for the different item types at each level of confidence.

Three different ROCs were derived. One ROC (see Figure 1) related confidence in responses to old items to confidence in responses to conjunction items, measuring a participant's memory for which actor performed each action.

Table 2
Proportions of "Yes" Responses in Experiment 1

	Old items		Conjunction items		Component items		New items	
Participant group	*M*	*SE*	*M*	*SE*	*M*	*SE*	*M*	*SE*
Nondistracted older adults	.59	.14	.40	.12	.26	.14	.11	.13
Nondistracted young adults	.65	.12	.31	.14	.19	.10	.10	.12
Young adults distracted at encoding	.56	.12	.41	.12	.23	.10	.16	.11
Young adults distracted at retrieval	.67	.10	.34	.14	.20	.13	.12	.13

Note. Old items were identical to items seen at encoding. Conjunction items involved a familiar actor performing an action that had been performed by a different actor at encoding. Component items involved either a familiar actor performing a new action or a familiar action performed by an unfamiliar actor. New items involved both a new actor and a new action. Performance with component items is reported primarily for purposes of comparison with prior studies in which this type of item was included (e.g., Jones & Jacoby, 2005) and is not analyzed further. Performance with component items generally mirrors performance with conjunction items but with lower overall levels of false recognition because only one of the two components of a component item was familiar.

A second ROC (see Figure 2) related confidence in responses to old items to confidence in responses to new items, measuring a participant's memory for the components of a recognition item. Old items involved a familiar actor and action, whereas new items involved an unfamiliar actor and action. Thus, detection of a new actor, a new action, or both would allow participants to discriminate between these two item types.

A third ROC (see Figure 3) related confidence in responses to conjunction items to confidence in responses to new items, measuring influences of the familiarity of the components of conjunction stimuli on the false recognition of those stimuli. This ROC is analogous to the corrected conjunction error rate computed by Jones and Jacoby (2005). ROCs are used to compare rates of acceptance of conjunction and new items at different levels of confidence, however, whereas the corrected conjunction error rate corresponds to a single point on each function.

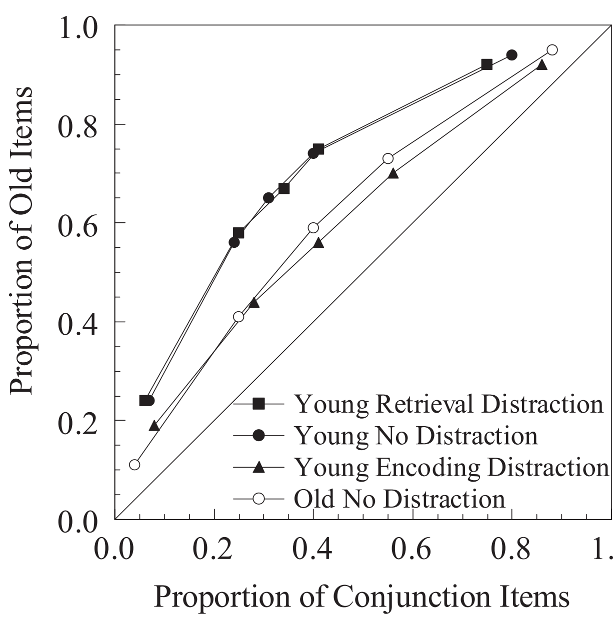

Figure 1. Receiver operating characteristics (ROC) functions representing discrimination of old and conjunction items in Experiment 1. Each function relates the probability of making a positive recognition response to an old item and to a conjunction item, with the criterion for what counts as a positive recognition response varying at different points on the function. In the leftmost point on each function, only an "absolutely sure yes" response is counted as a positive recognition response. In the second point, either an "absolutely sure yes" or a "pretty sure yes" is counted as a positive recognition response. An additional confidence level is then included in each subsequent point on each function, until only "absolutely sure no" responses are excluded. Better discrimination is indicated by an ROC function farther above and to the left of the central diagonal.

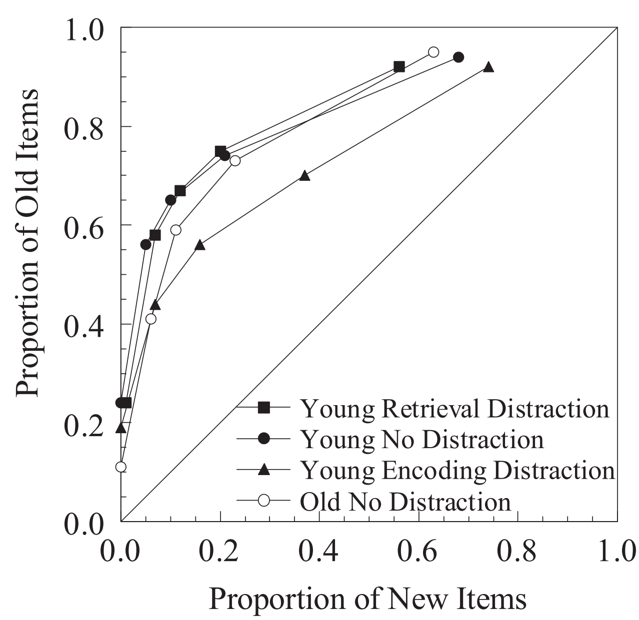

Figure 2. Receiver operating characteristics (ROC) functions representing discrimination of old items and new items in Experiment 1. Better memory for the components of a recognition stimulus (i.e., the actor and action) is indicated by ROC functions farther above and to the left of the central diagonal.

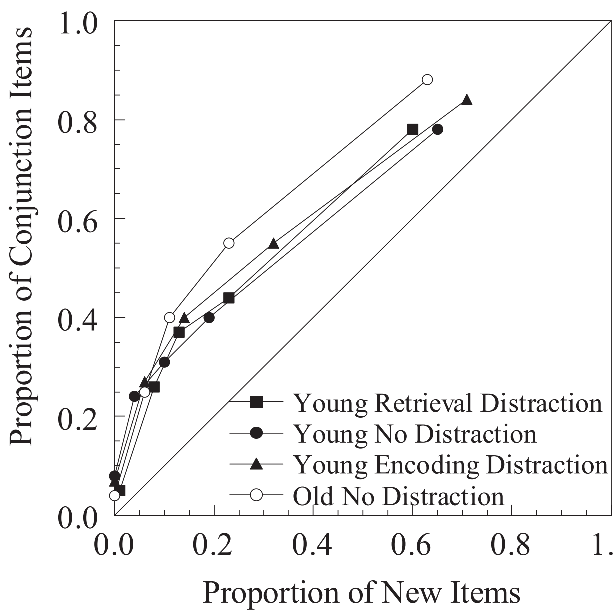

Figure 3. Receiver operating characteristics (ROC) functions representing the rates of (incorrect) acceptance of conjunction items and new items in Experiment 1. An ROC function above and to the left of the central diagonal would indicate influences of the familiarity of the actor and/or action in a conjunction stimulus in the absence of recollection of the contexts in which that actor and action were encountered. An ROC function that fell along the central diagonal, on the other hand, would indicate either that participants failed to receive a feeling of familiarity for the conjunction items or else that whenever participants received a feeling of familiarity for a conjunction item, they also recollected the source of that familiarity, allowing them to reject the conjunction item. Better binding performance is thus indicated by ROC functions falling closer to the central diagonal.

Older adults were compared separately to each of the young adult groups on each of these three ROC measures of recognition sensitivity. In order to perform inferential statistics on the ROCs, we computed an individual ROC for each participant, and the area under each participant's ROC was used as a summary measure of discrimination performance (Macmillan & Creelman, 2005).

Older adults versus young adults with no distraction. Old–conjunction discrimination was significantly better in young adults than in older adults, $t(30) = 2.11$, $p = .04$, $\eta^2 = .13$. This result is consistent with the results of Kersten et al. (2008), providing further evidence of an age-related deficit in the binding of actors and actions.

Old–new ROCs did not significantly differ between young and older adults, $t(30) = 0.61$, $p > .05$. This result suggests that older adults' deficit in old–conjunction discrimination stems from a binding deficit rather than a deficit in memory for the basic components of an event.

Conjunction–new ROCs revealed significantly greater differences in acceptance rates of conjunction and new items in older adults than in young adults, $t(30) = 2.54$, $p = .02$, $\eta^2 = .18$. This result suggests that the familiarity of the actor and action in a conjunction item led older adults to believe that they had seen that item before. Young adults, on the other hand, may have been more likely to recollect the contexts in which that actor and action had been encountered and thus to reject a novel combination of that actor and action.

Older adults versus young adults with distraction at encoding. Old–conjunction ROCs revealed no significant difference between older adults and young adults with distraction at encoding, $t(30) = 0.61$, $p > .05$. Thus, being distracted at encoding caused young adults later to perform no better than older adults at remembering which actor had performed a particular action.

Old–new ROCs, however, revealed a trend toward greater discrimination of old and new items in older adults than in distracted young adults, $t(30) = 1.65$, $p = .11$, $\eta^2 = .08$. This suggests that older adults were somewhat more successful than distracted young adults at encoding the basic components of an event.

Conjunction–new ROCs lend further support for this conjecture, revealing significantly greater differences in acceptance rates of conjunction and new items in older adults than in distracted young adults, $t(30) = 2.09$, $p < .05$, $\eta^2 = .13$. Older adults were thus more strongly influenced by the familiarity of the components of a conjunction item than were distracted young adults. This result suggests that older adults remembered the individual actors and actions they had seen but had difficulty remembering which actors went with which actions. In contrast, distracted young adults had reduced memory for the individual actors and actions, but their memory for which actor had performed an action was commensurate with their memory for those basic components in isolation.

Older adults versus young adults with distraction at retrieval. Old–conjunction discrimination was significantly better in young adults with distraction at retrieval than in older adults, $t(30) = 2.65$, $p = .01$, $\eta^2 = .19$. Thus, although distraction at encoding caused young adults to perform no better than older adults on this measure, distraction at retrieval did not reduce young adult performance to the same level.

Old–new ROCs did not significantly differ between young and older adults, $t(30) = 0.77$, $p > .05$. Thus, although there was a trend for young adults who were distracted at encoding to have greater difficulty than nondistracted older adults at discriminating old and new items, there was no such trend with young adults who were distracted at retrieval.

Conjunction–new ROCs revealed a trend toward greater differences in acceptance rates of conjunction and new items in older adults than in distracted young adults, $t(30) = 1.89$, $p < .07$, $\eta^2 = .11$. Thus, older adults were more strongly influenced by the familiarity of the components of the conjunction items than were any of the young adult groups, suggesting that aging and distraction have different effects on memory for events.

Discussion

The results of Experiment 1 revealed that young adults who were distracted at encoding and nondistracted older adults performed more poorly than nondistracted young adults at discriminating old events from novel conjunctions of familiar actors and actions. The similar deficits observed in young adults who were distracted at encoding and in nondistracted older adults, however, may stem from different mechanisms. Distracted young adults also exhibited a deficit at discriminating old items from new items, suggesting that their deficit at remembering which actor had performed an action stemmed from a more general deficit in memory for the basic components of an event. In contrast, older adults exhibited no deficit at discriminating old items from new items. Furthermore, older adults exhibited greater differences in their acceptance rates of conjunction items and new items than did any of the young adult groups, suggesting that older adults remembered the basic components of an event but had difficulty remembering how those components were paired at encoding, consistent with an age-related associative deficit.

Experiment 2

In Experiment 2, we compared effects of response pressure in young adults to effects of age on the binding of actors and actions. Older adults and one young adult group (the no-deadline condition group) had no response pressure. A second young adult group (the short-deadline condition group) was required to respond within 1 s of the onset of the test stimulus. These participants viewed an individual frame from each video clip, chosen to clearly portray the action and the actor's face, and were asked whether they had previously seen the depicted actor perform the depicted action.

Because the short-deadline condition differed from the no-deadline condition not only in the imposition of response pressure but also in the static test stimuli that were presented, a third young adult group (the long-deadline condition) viewed the same static test stimuli but were tested under reduced response pressure. These participants viewed each frame for 2 s, after which a response window of 1 s opened. Any differences in performance between the no-deadline condition and the short-deadline condition could thus be decomposed into differences due to test format and those due to response pressure.

Following the procedures used by Jones and Jacoby (2005), half of the encoding items, the low-frequency items, were presented only once, whereas the other half, the high-frequency items, were presented multiple times. Jacoby (1999) proposed that such frequency manipulations have independent effects on the familiarity of the components of a stimulus and on recollection of the contexts in which those components appeared. These effects would work in opposite directions in tests for recognition of conjunction items. In particular, conjunction items involving components that were seen (separately) on multiple occasions would lead to stronger feelings of familiarity for those individual components, but increased likelihood of recollection of the (separate) contexts in which those components had appeared would lead to increased likelihood of rejection of a novel conjunction of those components.

If older adults indeed have an associative deficit, then the effects of presentation frequency on the familiarity of individual components should overwhelm any effects of presentation frequency on recollection of the contexts in which those components were encountered. Thus, increased presentation frequency should lead older adults to be more likely to falsely recognize conjunction items because the components of those items would be more familiar. Because any effects of presentation frequency on binding would be muted, there would be little increased recollection of the contexts in which the components of the conjunction items were encountered, leading to an especially high rate of false recognition of conjunction items involving actors and actions that were seen (separately) on multiple occasions.

In young adults with no response pressure, on the other hand, increases in the familiarity of the components of the conjunction items were expected to be at least partially offset by increased recollection of the separate contexts in which those components were encountered. These young adults were thus expected to exhibit smaller increases in false recognition of conjunction items with increases in presentation frequency.

Predictions for effects of presentation frequency were less clear for the short-deadline group. This group was expected to show a deficit in remembering the basic components of an event, which would lead not only to reduced correct recognition of the old items but also to reduced false recognition of the conjunction items. This deficit was expected to be remediated to some extent by participants' having seen those components on multiple occasions, leading to increases in correct recognition of the old items but also (paradoxically) to increases in false recognition of the conjunction items. These increased feelings of familiarity for the conjunction items were expected to be at least partially offset by increased recollection of the contexts in which the components of those items were encountered. The relative magnitudes of the effects of presentation frequency on familiarity and recollection are difficult to predict, however.

If young adults who are subject to response pressure indeed have a deficit in remembering the basic components of an event, however, whereas older adults have an associative deficit, then one prediction that can clearly be made is that at both presentation frequencies, young adults who are subject to response pressure should be less likely than older adults to falsely recognize the conjunction items. In particular, regardless of presentation frequency, young adults who are subject to response pressure should be less likely than older adults to receive a feeling of familiarity for the components of the conjunction items, whereas they should be more likely than older adults to recollect, for any components that they remember, in what contexts those components appeared. Thus, young adults who were subject to response pressure were predicted to be less likely than older adults to falsely recognize both the low-frequency and high-frequency conjunction items.

Method

Participants. Seventy-two undergraduate students (*M* age = 19.25 years, *SD* = 0.93 years) participated for course credit. Twenty-four older adults (*M* age = 71.38 years, *SD* = 5.45 years) were recruited from lifelong learning classes and received $20 gift certificates. Participant characteristics are given in Table 3.

Stimuli and procedure. Participants viewed one of four different encoding lists of 124 video clips. The first two and last two video clips were filler items and were identical for each participant. The remaining 120 video clips were presented in a unique random order for each participant. Thirty of these video clips, the low-frequency items, were each seen only once. Thirty other video clips, the high-frequency items, were seen three times each.

One week later, participants returned for a recognition test that was identical to that of Experiment 1 for the no-deadline condition, except that participants were tested with a total of 80 video clips. Twenty of these were old items, 20 were conjunction items, 20 were new component items, and 20 were new items. For half of the old, conjunction, and new component items, the familiar components had been seen three times, whereas for half they had been seen only once.

Table 3
Participant Characteristics in Experiment 2

Variable	Young adults *M*	Young adults *SD*	Older adults *M*	Older adults *SD*	*p*
Age	19.25	0.93	71.38	5.45	<.001
Education	12.34	1.29	16.21	2.26	<.001
Health	4.14	0.68	4.33	0.76	.24
Medications	0.32	0.65	2.58	2.12	<.001
Vocabulary	27.40	3.87	35.17	3.91	<.001

Note. Symbol p = probability level associated with comparison between young and older participants; Education = number of years of education; Health = self-reported health on a scale of 1 (*poor*) to 5 (*excellent*); Medications = number of prescription medications currently being taken; Vocabulary = score out of 40 on the Shipley (1986) Vocabulary Test.

Participants in the short- and long-deadline conditions were instructed that they were to view static images depicting actors performing actions. They were told to press the "z" key when they remembered having previously seen the depicted actor perform the depicted action. Otherwise, they were instructed to press the slash key. Participants in the short-deadline condition were instructed to respond within 1 s after the presentation of the test item, or else the words "Too slow" would appear on the screen, and they would no longer be able to respond. Participants in the long-deadline condition were instructed that they were to view the test item for 2 s, after which they would hear a brief tone indicating that they had 1 s to respond.

Participants in the short-deadline and long-deadline conditions were given four practice trials so that they would become familiar with the response procedure. After the four practice trials, participants were shown an instruction screen describing the four trials and how they should have responded to them. Participants who received the "Too slow" message more than once were asked to perform the practice trials again. These participants were then allowed to continue to the test trials.

Results

The timeout rates in the short- (M = 6.7%, SD = 4.6%) and long- (M = 7.5%, SD = 7.0%) deadline conditions did not significantly differ, $t(46) = 0.46$, $p > .10$. Because the imposition of response deadlines was not consistent with collecting confidence ratings following "yes" or "no" recognition responses, discrimination performance was calculated in terms of differences in the proportions of "yes" responses to the different item types. These proportions of "yes" responses are in Table 4. As in Experiment 1, three different measures of discrimination performance were computed. One measure represented a participant's ability to bind actors with actions, and we computed it by subtracting the proportion of false alarms to conjunction items from the proportion of hits to old items (see Figure 4). A second measure represented a participant's memory for the components of a recognition stimulus, and we computed it by subtracting the proportion of false alarms to new items from the proportion of hits to old items (see Figure 5). Finally, a third measure represented influences of the familiarity of the components of a conjunction stimulus in the absence of recollection of the contexts in which those components were encountered, and we computed it by subtracting the proportion of false alarms to new items from the proportion of false alarms to conjunction items (see Figure 6).

Older adults versus young adults with no response pressure. An analysis of variance (ANOVA) on old–conjunction discrimination revealed a main effect of participant group, $F(1, 46) = 12.94$, $p = .001$, mean square error (MSE) = .072, $\eta_p^2 = .22$, with better discrimination in nonpressured young adults than in older adults. There was also a main effect of presentation frequency, $F(1, 46) = 12.03$, $p = .001$, $MSE = .044$, $\eta_p^2 = .21$, with greater discrimination of old and conjunction items in the high-frequency condition. There was no significant interaction ($p > .05$).

An ANOVA on old–new discrimination revealed a main effect of participant group, $F(1, 46) = 9.28$, $p = .004$, $MSE = .049$, $\eta_p^2 = .17$, with better discrimination in young adults than in older adults. There was also a main effect of presentation frequency, $F(1, 46) = 110.72$, $p < .001$, $MSE = .025$, $\eta_p^2 = .71$, with greater

Table 4
Proportions of "Yes" Responses in Experiment 2

Participant group	Old items *M*	Old items *SE*	Conjunction items *M*	Conjunction items *SE*	Component items *M*	Component items *SE*	New items *M*	New items *SE*
				Low-frequency items				
Older adults with no deadline	.55	.29	.41	.22	.27	.21	.13	.14
Young adults with no deadline	.63	.20	.36	.21	.13	.11	.05	.06
Young adults with a short deadline	.38	.24	.32	.20	.29	.18	.19	.14
Young adults with a long deadline	.46	.20	.37	.21	.25	.14	.06	.07
				High-frequency items				
Older adults with no deadline	.91	.11	.69	.21	.40	.19		
Young adults with no deadline	.95	.12	.46	.25	.21	.14		
Young adults with a short deadline	.67	.20	.52	.29	.45	.21		
Young adults with a long deadline	.82	.18	.47	.23	.37	.18		

Note. New items were never presented at encoding, and thus presentation frequency is not meaningful with respect to these items. However, these items are listed with the low frequency items for ease of comparison.

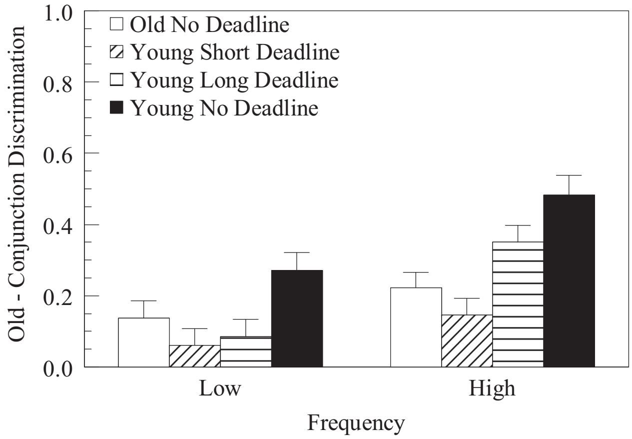

Figure 4. Discrimination of old items and conjunction items in Experiment 2. Each bar represents the difference between the proportion of "yes" responses to old items and the proportion of "yes" responses to conjunction items. Better binding performance is thus indicated by larger difference scores. Error bars represent the standard error of each mean difference score.

discrimination of old items from new items when old items were seen three times as opposed to only once. There was no significant interaction ($p > .05$).

An ANOVA on conjunction–new difference scores did not reveal a significant main effect of participant group ($p > .05$). It did reveal a significant main effect of item frequency, however, $F(1, 46) = 34.91$, $p < .001$, $MSE = .025$, $\eta_p^2 = .43$, and this main effect was moderated by a significant interaction of participant group and item frequency, $F(1, 46) = 7.92$, $p = .007$, $MSE = .025$, $\eta_p^2 = .15$. There was not a significant difference between the two participant groups on differentiation of low-frequency conjunction items from new items ($p > .05$). Older adults, however, exhibited

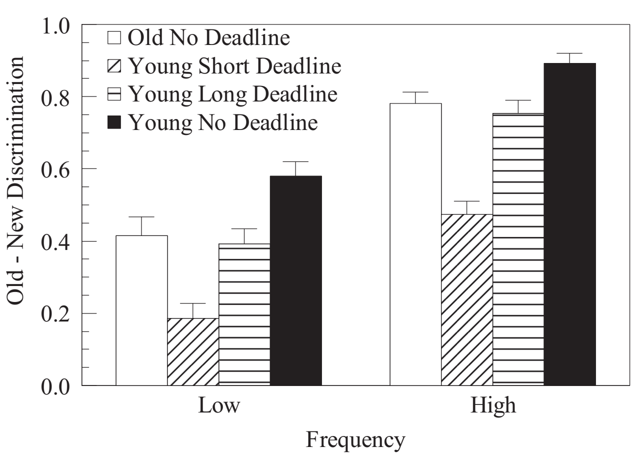

Figure 5. Discrimination of old items and new items in Experiment 2. Each bar represents the difference between the proportion of "yes" responses to old items and the proportion of "yes" responses to new items. Better memory for the components of a recognition stimulus is indicated by larger difference scores. Error bars represent the standard error of each mean difference score.

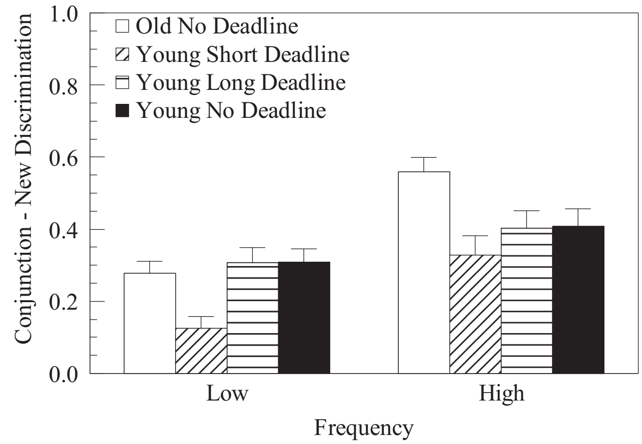

Figure 6. Differences in the rates of (incorrect) acceptance of conjunction items and new items in Experiment 2. Each bar represents the difference between the proportion of "yes" responses to conjunction items and the proportion of "yes" responses to new items. These measures are thus analogous to the corrected conjunction error rates reported by Jones and Jacoby (2001, 2005), representing influences of the familiarity of the actor and action in a conjunction stimulus in the absence of recollection of the contexts in which that actor and action were encountered. Because the correct response to both conjunction items and new items is "no," better binding performance is indicated by lower difference scores. Error bars represent the standard error of each mean difference score.

significantly greater differences in their acceptance rates of high-frequency conjunction items and new items than did young adults, $t(46) = 2.38$, $p = .02$, $\eta^2 = .11$, indicating that older adults were more strongly influenced by the familiarity of the components of the conjunction items.

Older adults versus young adults with a short-response deadline. An ANOVA on old–conjunction discrimination did not reveal any significant effects (all ps $> .05$). The lack of significant effects involving the participant group variable indicates that time-pressured young adults performed similarly to older adults at remembering which actor had performed each action.

An ANOVA on old–new discrimination revealed a significant main effect of presentation frequency, $F(1, 46) = 97.44$, $p < .001$, $MSE = .026$, $\eta_p^2 = .68$. There was also a significant main effect of participant group, $F(1, 46) = 31.80$, $p < .001$, $MSE = .054$, $\eta_p^2 = .41$, with greater old–new discrimination in older adults than in time-pressured young adults. There was no significant interaction ($p > .05$).

An ANOVA on conjunction–new difference scores revealed a significant main effect of presentation frequency, $F(1, 46) = 45.48$, $p < .001$, $MSE = .031$, $\eta_p^2 = .50$, with greater differences between acceptance rates of conjunction items and new items when those conjunction items were composed of actors and actions seen separately on three occasions as opposed to only once. There was also a significant main effect of participant group, $F(1, 46) = 17.11$, $p < .001$, $MSE = .051$, $\eta_p^2 = .27$, with older adults exhibiting greater differences in their acceptance rates of conjunction items and new items than did young adults. There was no significant interaction ($p > .05$). The results of time-pressured young adults were thus similar to the results of young adults distracted at encoding in Experiment 1, with both groups showing poorer old–new discrimination than older adults but lower rates of conjunction errors than older adults after baseline levels of false recognition were controlled.

Older adults versus young adults with a long-response deadline. An ANOVA on old–conjunction discrimination did not reveal a significant main effect of participant group ($p > .05$). It did reveal a main effect of presentation frequency, however, $F(1, 46) = 15.88$, $p < .001$, $MSE = .046$, $\eta_p^2 = .26$, and this main effect was moderated by a significant interaction of participant group and item frequency, $F(1, 46) = 4.24$, $p = .05$, $MSE = .046$, $\eta_p^2 = .08$. There was no significant difference between the two participant groups on discrimination of low-frequency old and conjunction items ($p > .05$). Young adults, however, exhibited significantly greater discrimination of high-frequency old and conjunction items than did older adults, $t(46) = 2.03$, $p = .05$, $\eta^2 = .08$.

An ANOVA on old–new discrimination revealed only a significant main effect of presentation frequency, $F(1, 46) = 106.44$, $p < .001$, $MSE = .030$, $\eta_p^2 = .70$. There were no significant effects involving the participant group variable (both ps $> .05$), indicating that the two groups were well matched in terms of memory for the individual components of a recognition stimulus.

An ANOVA on conjunction–new difference scores did not reveal a significant main effect of participant group ($p > .05$). It did reveal a significant main effect of presentation frequency, however, $F(1, 46) = 40.82$, $p < .001$, $MSE = .021$, $\eta_p^2 = .47$, and this main effect was moderated by a significant interaction of participant group and presentation frequency, $F(1, 46) = 9.92$, $p = .003$, $MSE = .021$, $\eta_p^2 = .18$. There was no significant difference between the two participant groups on differentiation of low-frequency conjunction items from new items ($p > .05$). Older adults, however, exhibited significantly greater differences in their acceptance rates of high-frequency conjunction items and new items than did young adults, $t(46) = 2.49$, $p = .02$, $\eta^2 = .12$, indicating that older adults were more strongly influenced by the familiarity of the components of the conjunction items.

Discussion

The results of Experiment 2 revealed that older adults and time-pressured young adults performed more poorly than did nonpressured young adults at discriminating old items from novel conjunctions of familiar actors and actions. As in Experiment 1, however, other results suggest that the similar deficits in discriminating old and conjunction items observed in time-pressured young adults and in nonpressured older adults may stem from different mechanisms. In particular, time-pressured young adults also showed a deficit in remembering the basic components of an event. Older adults, on the other hand, performed just as well as young adults in the long-deadline condition at discriminating old and new items, and they were more strongly influenced by the familiarity of the components of the conjunction items than were any of the young adult groups. These results suggest that they remembered the basic components of an event but had difficulty remembering how those components went together, consistent with an age-related associative deficit.

General Discussion

The present results suggest that it may be possible to mimic only some characteristics of the performance of older adults in young adults through the imposition of distraction and response pressure. In particular, young adults who were distracted at encoding and young adults who were subject to time pressure at retrieval performed similarly to older adults at discriminating old events from novel conjunctions of familiar actors and actions. These two groups of young adults performed differently than older adults in other respects, however. In particular, when compared with older adults, distracted and time-pressured young adults showed reduced discrimination of old items from items involving new actors and actions, suggesting that they were less successful than older adults at remembering these basic components of an event. Furthermore, older adults showed greater differences in their rates of acceptance of conjunction and new items than did any of the young adult groups, suggesting that older adults were successful at encoding the actor and action that later appeared in a conjunction item but had difficulty remembering how those actors and actions went together.

Relation to Findings From Other Paradigms

The present results more closely resemble results from the paired-associates learning paradigm than they do results from the conjunction memory paradigm. In particular, young adults exhibited smaller differences in their rates of acceptance of conjunction and new items than did older adults, suggesting that young adults were sometimes able to recollect the (separate) contexts in which the actor and action in a conjunction item had appeared at encoding and to reject the conjunction item on that basis. These results are similar to results from Castel and Craik (2003), Kilb and Naveh-Benjamin (2007), and Light, Patterson, Chung, and Healy (2004) who found that young adults were more likely than older adults to reject a novel pairing of two familiar words.

The present results differ from those of Jones and Jacoby (2005), however, who found that young adults were able to use recollection to reject a conjunction of familiar word fragments only when those fragments had appeared in the wrong modality. Barring the use of modality information, young adults exhibited a conjunction error rate just as high as that of older adults. These results thus suggest that young adults have difficulty rejecting a conjunction word solely on the basis of the pairing of its fragments.

The present results suggest that the key feature that differentiates the conjunction memory paradigm from the paired-associates learning paradigm is not the degree to which the components of a test stimulus are fused together but rather the extent to which those components retain their separate identities in the resulting fusion and thus can be parsed out by human observers. Similar to the components of the compound words used in the conjunction memory paradigm, the actors and actions in the present events were mutually interdependent, with the actions dependent upon an actor's body for their realization and the actor's body only appearing in the context of performing that action.

Unlike the components of a compound word, however, the actor and action in an event are processed as separate entities by human observers, allowing one to use the actor in an event as a cue to retrieve other events involving that same actor and to use the action in an event as a cue to retrieve other events involving that same action. In contrast, although a compound word is composed of word fragments (e.g., *black*, *mail*) that have their separate meanings, the combination of those fragments carries a more specific meaning. This may encourage participants to treat those fragments as a unit rather than as separable entities. Other researchers who have employed the conjunction memory paradigm (e.g., Kroll, Knight, Metcalfe, Wolfe, & Tulving, 1996; Reinitz, Verfaellie, & Milberg, 1996) have also used stimuli (e.g., faces) that tend to be processed holistically rather than in terms of their individual components. This may explain why participants in the conjunction memory paradigm would have difficulty using one of the components of a conjunction item to retrieve the other component with which it had been previously paired at encoding.

Implications for an Age-Related Associative Deficit

The present results are consistent with the theory of an age-related associative deficit proposed by Naveh-Benjamin (2000). In particular, older adults had greater difficulty than did young adults at remembering the pairings of component stimuli, even when they performed just as well as young adults at remembering those components in isolation. Moreover, the present results suggest that this deficit is distinct from impairments in young adult performance associated with distraction and time pressure. These impairments appear to center on memory for the individual components of a stimulus, with any impairments in memory for associations among those components commensurate with memory for the components themselves.

It may be possible to explain this pattern of results in terms of theories of the brain circuitry underlying the binding of information in memory. Mitchell, Johnson, Raye, and D'Esposito (2000) proposed that binding in memory is subserved by a frontal–hippocampal circuit, on the basis of neuroimaging results showing greater involvement of prefrontal cortex and the hippocampus in memory for conjunctions of stimulus components than in memory for those components in isolation. Kilb and Naveh-Benjamin (2007) have further proposed that prefrontal cortex is involved in strategic, attention-based processing of associations among stimuli, whereas the hippocampus is involved in more automatic, longer term consolidation of associations in memory (see Shing, Werkle-Bergner, Li, & Lindenberger, 2008, for a related view). Distraction may thus primarily impact strategic processes in prefrontal cortex without directly impacting the more automatic processes of the hippocampus.

Because distraction had its most powerful effects at encoding in Experiment 1, it follows that distraction impaired the strategic encoding of relations among actors and actions. Although strategic encoding implies the use of sophisticated mnemonic strategies, it could simply involve maintaining for some period of time in working memory a visual image of an actor's face and a visual or verbal representation of the action he or she performed. This active maintenance of the information to be bound in memory may have been more difficult in the face of a secondary, distractor task. However, to the extent that participants were able to simultaneously maintain in working memory both the actor's face and the action performed, despite any reduction in attentional resources associated with the distractor task, these two pieces of information would be associated in the more automatic binding processes of the hippocampus. Thus, consistent with the view of Moscovitch (2008), the binding processes of the hippocampus are affected by a distractor task only via the ability of prefrontal cortex to maintain attention to the relevant stimulus components, leading to binding performance commensurate with memory for those components in isolation.

Prefrontal cortex has also been proposed to be involved in evaluation of the results of retrieval processes from long-term memory (Van Petten, Luka, Rubin, & Ryan, 2002). Although distracting young adults at retrieval did not result in memory impairments in the present research, time pressure at retrieval did impact young adults' abilities to discriminate old events from novel conjunctions of familiar actors and actions. Again, however, this deficit appeared to stem from an impairment in memory for the components of an event. In particular, time-pressured young adults also showed reduced discrimination of old events from new events involving new actors and actions.

Moreover, time-pressured young adults exhibited a smaller difference between their acceptance rates of low-frequency conjunction items and new items than did any of the other participant groups. This result suggests that time-pressured young adults failed to receive a feeling of familiarity for the conjunction items, presumably because they were not able to retrieve within the available time frame a memory trace of either their earlier encounter with that same actor or their earlier encounter with that same action. Time-pressured young adults exhibited increased false recognition of conjunction items when the actors and actions appearing in those items had been encountered on multiple occasions. They still exhibited a lower conjunction error rate than did older adults with these items, however.

These results are somewhat surprising because time pressure has been suggested to primarily impact recollection, while leaving unaffected the relatively faster, more automatic influences of familiarity (Jones & Jacoby, 2001). Qualitatively similar results have been obtained by Light et al. (2004), however, with the paired-associates learning paradigm. In particular, Light et al. found that young adults with a short deadline exhibited a smaller difference in their acceptance rates of low-frequency conjunction items and new items (M = .12) than did either young adults with a long deadline (M = .21) or older adults with a long deadline (M = .25). Thus, response deadlines do appear to have an impact on familiarity, at least in the context of a judgment made about whether two stimuli appeared together at encoding.

A possible explanation for these different results is that familiarity processes are unaffected by response deadlines in the context of relatively simple stimuli, such as the isolated compound words employed by Jones and Jacoby. The interpretation of complex stimuli, however, may take sufficiently long that recollection has already started to take place by the time those stimuli have been interpreted. For example, one may be able to perceive the face of an actor in a conjunction item relatively quickly, allowing one to begin probing long-term memory for prior events involving that actor before one is able to interpret the action depicted in the static image. Thus, recollection of the (different) prior context in which one has encountered the same actor may occur in about the same time frame as receiving a feeling of familiarity for an action, allowing one to overcome that feeling of familiarity to reject the conjunction item.

In contrast to distraction and response deadlines, which may primarily impact prefrontal cortical functioning, aging may have its largest impact on the hippocampus. Thus, older adults may show relatively intact memory for the individual components of a stimulus, because those memories are not dependent on the hippocampus. Aging may instead primarily impact hippocampally mediated associative processes, resulting in impairments in memory for the pairings of stimuli. It of course remains possible that older adults also have impairments in prefrontal cortical functioning, given the evidence of age-related structural and functional changes in this brain area (e.g., Mitchell et al., 2000; Raz, 2000). Older adults appear to have a deficit in binding above and beyond any deficits in attentional resources, however, suggesting that they have a distinct hippocampally mediated associative deficit.

Conclusions

The results of the present research suggest that aging leads to a deficit in the binding of actors and actions that is distinct from any effects of distraction and response pressure on this binding process. These results indicate that older adults may be especially prone to false memories in which an actor is remembered as having performed an action that had actually been performed by somebody else. This would have implications for the everyday functioning of older adults, suggesting that older adults may have difficulty remembering who had talked to them earlier that day, who had lent them money, and possibly who they had seen perform a criminal act.

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