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Age-Related Binding Deficits and the Content of False Memories

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The authors examined effects of age-related binding deficits on feature information in false memories for imagined objects (e.g., *lollipop*) that were similar in shape to seen objects (e.g., *magnifying glass*). In Experiment 1, location memory for seen objects was lower in older than younger adults and lower still in old-old than young-old adults. Imagined objects, when falsely called seen, were less likely to be attributed to the location of similar seen objects (i.e., congruent attributions) by old-old than young-old adults. In Experiment 2, for younger adults, displaying seen objects for less time (1 s vs. 4 s) reduced both location memory for seen objects and congruent attributions for false memories. Thus, binding deficits may influence the specific content of false memories.

Keywords: reality monitoring, source monitoring, false memories, feature binding, aging and memory

Normal aging is associated with an apparent paradox: With age, adults remember fewer, or less about, actual events, yet they falsely remember more events that never occurred. Evidence for the first part of the paradox comes from studies showing that older adults are impaired relative to younger adults at recalling various source or contextual features of past events, such as color (Park & Puglisi, 1985), modality (i.e., seen or heard, McIntyre & Craik, 1987), and location (Chalfonte & Johnson, 1996; Light & Zelinski, 1983; Mitchell, Johnson, Raye, Mather, & D'Esposito, 2000; Pezdek, 1983). At the same time, older adults are more susceptible than younger adults to false memories for events that share perceptual, conceptual, or both feature types with actually experienced events (e.g., Balota et al., 1999; Henkel, Johnson, & De Leonardis, 1998; Koutstaal, 2003; Koutstaal & Schacter, 1997; Norman & Schacter, 1997; see Schacter, Koutstaal, & Norman, 1997, for a review; but see Butler, McDaniel, Dornburg, Price, & Roediger, 2004, for evidence that age differences are not inevitable). This paradox can be resolved by positing that aging produces a deficit in cognitive processes involved in remembering the features of actual events, and this, in turn, impairs discrimination between similar events (e.g., between an event that really happened and a similar one that did not).

Behavioral (Chalfonte & Johnson, 1996; Mitchell, Johnson, Raye, Mather, & D'Esposito, 2000; Naveh-Benjamin, 2000; Naveh-Benjamin, Hussain, Guez, & Bar-On, 2003) and neuroimaging (Mitchell, Johnson, Raye, & D'Esposito, 2000) evidence is accumulating to suggest that aging disrupts the processes by which multiple distinct features (e.g., color, location, shape) of complex events are associated with one another in memory (i.e., binding processes). Binding deficits would result in memories of actual past experiences that include less feature information, because a smaller subset of the features of those experiences would become activated together in response to retrieval cues. According to the source-monitoring framework (SMF; Johnson, Hashtroudi, & Lindsay, 1993; Johnson & Raye, 2000), binding deficits would also contribute to an increased susceptibility to false memories. That is because the source of memories is inferred on the basis of, in part, the quality and quantity of activated feature information. For example, a statement may be attributed to a speaker on the basis of whether one's memory for the statement includes voice information associated with that speaker (Johnson, Foley, & Leach, 1988). By reducing the amount of feature information recalled about events, binding deficits increase the risk that memories will fail to be attributed to their true source. More specifically, binding deficits should increase the misattribution of memories to sources that are associated with some of the same features as the memories' actual source, because remembered feature information will be less likely to include information about features that distinguish between similar sources.

For example, Henkel et al. (1998) found that when participants imagined line drawings of objects (e.g., *lollipop*), they were more likely to falsely remember seeing drawings of those objects if they actually had seen a drawing of a similarly shaped object (e.g., *magnifying glass*) than if they had not. Furthermore, the impact of perceiving a similar object was greater for older than younger adults. Henkel et al. explained the age difference by proposing that for older compared with younger adults, shape features of seen objects may not have been as strongly bound to other features of those objects that could help to identify the true source of the shape features. For example, shape features may have been less strongly bound to conceptual features, which differed between similarly shaped but conceptually distinct objects; or, the multiple shape features within a given object may have been less strongly bound together, making it difficult to discriminate between objects that shared some, but not all, shape features. As a consequence of reduced binding, shape features of seen objects were more often misattributed to similar imagined objects by older than younger

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adults. The misattribution of shape features of seen objects to imagined objects increased the misattribution of imagined objects to perception, because shape information tends to be greater for perceived than imagined events (i.e., it is more specific or there is more of it; e.g., Brewer, 1988; Conway, Pleydell-Pearce, White-cross, & Sharpe, 2003; Hashtroudi, Johnson, & Chrosniak, 1990; Johnson, Foley, Suengas, & Raye, 1988; Johnson & Raye, 1981; Johnson, Raye, Foley, & Kim, 1982; McGinnis & Roberts, 1996; Suengas & Johnson, 1988).

Here we are concerned with how age-related binding deficits may affect not only the likelihood of false memories but also the specific feature information in false memories. Much research, most of it conducted with college-age participants, has shown that false memories, like memories of actual events, may include specific information about a variety of features, such as perceptual qualities and thoughts or feelings elicited by events (e.g., Lampinen, Copeland, & Neuschatz, 2001; Mather, Henkel, & Johnson, 1997; Schooler, Gerhard, & Loftus, 1986; for reviews see Lampinen, Neuschatz, & Payne, 1999; Payne, Neuschatz, Lampinen, & Lynn, 1997). The specific content of memories (whether real or false) is important because it may affect how confidently memories are held (Johnson, Nolde, & De Leonardis, 1996) and how other people judge their origin (e.g., Johnson, Bush, & Mitchell, 1998; Johnson & Suengas, 1989; Keogh & Markham, 1998) and accuracy (Bell & Loftus, 1988, 1989).

To appreciate how binding deficits might affect the content of false memories, consider one source of that content: memories of similar perceived events. The results of Henkel et al. (1998), described above (see also Henkel & Franklin, 1998), suggest that false memories may include similar feature information from actually perceived events. We recently examined the possibility, among college-age adults, that false memories of imagined objects might include additional specific details that were part of similar seen objects (Lyle & Johnson, 2006, Experiment 1A). Participants always imagined objects in the center of a computer screen, and each seen object was presented in one of the four corners of the screen. When participants remembered seeing objects, they were asked to indicate the corner in which the object had appeared. Replicating Henkel and colleagues, imagined objects were more likely to be called seen when a similar object had been seen versus not been seen. Furthermore, we found that false memories of imagined objects tended to include location information congruent with that assigned to a similar seen object. For example, if *magnifying glass* was seen in the lower left corner, and the imagined object *lollipop* was falsely remembered as seen, participants tended to report that *lollipop* had been in the lower left corner. This was true even though the location information associated with imagined objects during the initial imagination trials was never similar to that associated with seen objects during perception trials.

On the basis of the tenets of the SMF, and elaborating on ideas put forth by Henkel and colleagues (Henkel & Franklin, 1998; Henkel et al., 1998), we (Lyle and Johnson, 2006) proposed that when tested on an imagined object, some features of a seen object (e.g., shape features) may become activated by virtue of their similarity to features of the imagined object. Critically, other features of the seen object (e.g., location) also may become activated, not because they are themselves similar to those of the imagined object, but because they are bound to the similar features; this occurs because bound features tend to become activated together (e.g., Nyberg, Habib, McIntosh, & Tulving, 2000). Because the features become activated when participants are tested on the imagined object, and because at least some of them are similar to the features of the imagined object, the features may be misattributed to the imagined object. The inadvertent activation and misattribution of features was dubbed the "importation" of features from one event into another, and we suggested that perceived events, which consist of many possible features, might potentially be a rich source of imported information for false memories.

Age-related binding deficits should influence the specific content of false memories, because according to our earlier proposal (Lyle & Johnson, 2006), although some features inadvertently become activated owing to their similarity to the features of test events (and this effect of similarity may be equally strong for younger and older adults), other features become activated only to the extent to which they are bound to the similar features. Therefore, an age-related deficit in binding shape and location may mean that older adults' false memories are less likely than those of younger adults to import the extra feature of location from memories of similar seen objects, because for older adults, the location of similar seen objects is less likely to become activated when imagined objects are tested. This may be the case even though older adults' memories of imagined objects may be, as Henkel et al. (1998) argued, more likely to import shape features of similar seen objects, because also as a result of binding deficits, distinctive conceptual features of seen objects are less likely to become activated along with shape features. To explore this possibility, in Experiment 1, we ran older (i.e., 60 years of age or older) and younger (i.e., college-age) adults in a procedure similar to that in which we previously ran only younger adults, as described above (Lyle & Johnson, 2006, Experiment 1A).

In Experiment 2, we examined whether, among younger adults, it was possible to experimentally reduce memory for the conjunction of shape and location by reducing the duration of seen events and thereby reduce the importation of location into false memories of similar imagined events. In other words, we sought to experimentally induce binding deficits in younger adults in order to see whether the manipulation mirrored the effect of aging.

Experiment 1

Method

Participants. Twenty-four Yale University students (13 women, 11 men; mean age = 20.8 years, *SD* = 3.60 years; median age = 19.5, range = 18–30 years) participated in return for money or credit in an introductory psychology course. Thirty-two healthy older adults age 60 or older (21 women, 11 men; mean age = 76.4 years, *SD* = 8.28 years; median age = 79.0, range = 61–93 years) were recruited from the community to serve as paid participants. All participants reported themselves to be in good health and had normal or corrected-to-normal vision and hearing.

The mean number of completed years of education was higher for older (M = 17.0, SD = 2.74) than younger adults (M = 13.5, SD = 1.72), $t(54)$ = 5.54. All participants completed the Vocabulary subscale of the Wechsler Adult Intelligence Scale—Revised (Wechsler, 1987). Out of a maximum score of 30, the mean scores were 23.0 (SD = 4.50) for younger adults and 23.8 (SD = 3.74) for older adults. The average score for older participants on the Mini-Mental State Examination (Folstein, Folstein, & McHugh, 1975) was 28.8 (SD = 1.47) out of 30.

Materials and procedure. The materials were the same as in Lyle and Johnson (2006, Experiment 1A). Stimuli consisted of 80 slides adapted from a pool developed by Henkel and colleagues (Henkel & Franklin, 1998; Henkel et al., 1998) and were presented via computer with Microsoft PowerPoint. For perception trials, each of 40 slides showed a black-and-white line drawing of an object in one of the four corners of the screen with its name directly below it. Drawings were pseudorandomly assigned to corners with the restriction that each corner was assigned to one quarter of the objects from visual and control pairs (see below). For 40 imagination trials, only the name of an object appeared on the slide, and it always appeared just below the center of the screen.

Although objects were presented individually on perception and imagination trials, for the purpose of constructing the slide sequence, each object was paired with a single other object that appeared elsewhere in the slide sequence. In each pair, one object was seen on a perception trial, and one object was imagined on an imagination trial. In visual pairs, the imagined object was visually similar (i.e., similar in shape), but otherwise unrelated, to the seen object (e.g., *lollipop* and *magnifying glass*) on the basis of physical-resemblance ratings collected by Henkel and Franklin (1998) from a different group of participants. In control pairs, imagined objects were arbitrarily paired with seen objects to which they had no obvious relation (e.g., *belt* and *feather*). Normative data collected by Henkel and Franklin showed that the objects assigned to the two pair types do not differ, on average, in the ease with which they can be imagined or their physical complexity. There were 20 visual and 20 control pairs.

Participants received the 80 intermixed perception and imagination trials in pseudorandom order with the restriction that there was a minimum of 10 trials between pair members. For a random half of the pairs of each type, the seen member occurred first in the order of trials, and for the other half, the imagined member occurred first. Two orderings were constructed such that each object appeared before and after its pair member for an equal number of participants.

Slides were presented for 7 s each. On perception trials, participants stated out loud the corner filled by the object and how long they estimated it took our artist to draw the picture. On imagination trials, participants imagined a simple line drawing of the object whose name appeared just below the center of the screen. They were told to imagine the drawing appearing directly above the name of the object, just as actual drawings appeared above the names of objects on perception trials. After imagining the drawing, they stated their estimate of how long it would take the same artist who drew the pictures on perception trials to draw the picture they had imagined. All responses during the slide sequence were made verbally and recorded by the experimenter. The orienting task was used during the slide sequence to encourage participants to encode shape features of seen and imagined objects. Participants were given three perception and three imagination trials for practice. All participants understood the instructions readily.

After the slide sequence, there was a 15-min retention interval, during which participants completed some lab-related paperwork. A 15-min retention interval was used, rather than a 48-hr one as in Lyle and Johnson (2006, Experiment 1A), because earlier work by Henkel et al. (1998) showed that older adults' memory for stimuli like these was poor after 48 hr. At the conclusion of the retention interval, participants were given a surprise source memory test. The test consisted of the names of the 80 seen and imagined objects from the slide sequence plus 40 new objects presented in one pseudorandomly intermixed order. The new objects were selected, insofar as possible, to have no relation to any of the seen or imagined objects. Pair members from visual and control pairs were tested at least eight trials apart. For a randomly chosen half of the pairs of each type, the imagined object from the pair was tested first, and for the other half, the seen object was tested first.[1] Next to each object name on the test form were the response options *perceived*, *imagined*, or *new*. The perceived option was followed by the four additional response options of *upper left*, *lower left*, *upper right*, or *lower right*. Participants indicated whether each object had been perceived, imagined, or was new. For those objects participants called perceived, they furthermore indicated the corner in which the object appeared.

Results

All reported differences were significant at the $p < .05$ level.

Recognition memory. Table 1 shows, for each of the four types of objects in the slide sequence (i.e., visual–imagined, visual–seen, control–imagined, and control–seen), the mean proportion correctly recognized as old (i.e., called either seen or imagined) minus the proportion of new objects called old. These corrected recognition scores for each participant were entered into a 2 (age: younger vs. older) × 2 (source: perceived vs. imagined) × 2 (pair type: visual vs. control) mixed-design analysis of variance (ANOVA) in which the first factor was between-participants and the last two factors were within-participant. There was a main effect of age, $F(1, 54) = 16.62$, $MSE = .07$; overall, younger participants had higher recognition memory ($M = .85$) than did older adults ($M = .71$). The higher recognition scores for younger adults were partly due to the fact that older adults falsely identified a larger proportion of new objects as old ($M = .05$) than did younger adults ($M = .02$); this difference was significant, $t(54) = 2.03$. Both younger and older adults attributed about half of the falsely recognized objects to perception (Ms = .54 and .50, respectively) and half to imagination (Ms = .46 and .50, respectively).

The analysis of recognition memory also yielded significant main effects of source, $F(1, 54) = 146.00$, $MSE = .02$, and pair type, $F(1, 54) = 8.99$, $MSE = .01$, but these were qualified by a significant interaction between the two factors, $F(1, 54) = 4.33$, $MSE = .02$. The effect of source was the same as in other studies comparing imagined and perceived events (e.g., Durso & Johnson, 1980), whereby recognition of imagined objects ($M = .91$) was better than of seen objects ($M = .66$). The interaction with pair type arose because, although recognition memory did not differ reliably for visual–imagined ($M = .90$) and control–imagined ($M = .88$) objects, recognition memory for visual–seen objects ($M = .61$) was, unexpectedly, significantly lower than for control–seen objects ($M = .66$), $t(55) = 3.05$.

Imagined–perceived source errors. To investigate differences in imagined–perceived source errors for objects from different conditions, we calculated, of the objects in each condition correctly recognized as old, the proportion attributed to the incorrect source (i.e., imagined objects called seen or seen objects called imagined; see Table 2). This measure conditionalizes imagined–perceived source errors on correct recognition in each condition. Some researchers have suggested that interpreting differences in source memory can be difficult when recognition levels vary between conditions (Batchelder & Riefer, 1990; Bayen & Murnane, 1996), even when source memory is conditionalized on recognition. However, as can be seen by comparison of Tables 1 and 2, source errors differ between conditions that have similar

[1] The order in which pair members were presented on the source memory test and in the slide sequence did not reliably influence the effects of interest in this article; therefore, those two variables are not discussed further.

Table 1
Mean Proportion Correct Recognition (With Standard Errors) as a Function of Age, Source, and Pair Type in Experiment 1

Age and source	Pair type: Visual	Control	*M*
Younger			
Imagined	.96 (.01)	.95 (.01)	.96
Seen	.71 (.04)	.76 (.04)	.74
M	.84	.86	
Older			
Imagined	.83 (.03)	.87 (.02)	.85
Seen	.53 (.04)	.60 (.03)	.57
M	.68	.74	

levels of recognition (visual–imagined vs. control–imagined for both younger and older adults). Furthermore, Henkel and Franklin (1998) analyzed data from a similar procedure using both conditional probabilities and multinomial models that independently examine source discriminability and item detectability and obtained similar results using both methods.

The proportion of source errors in each condition from each participant was entered into an ANOVA with the same design as the one used for recognition memory. There were significant main effects of age, $F(1, 54) = 21.15$, $MSE = .02$, and pair type, $F(1, 54) = 45.0$, $MSE = .004$, and most important for present purposes, a significant interaction between the two factors, $F(1, 54) = 18.86$, $MSE = .004$. The interaction between age and pair type indicated that younger and older adults' source memory was differentially impaired by seeing or imagining a similar object. Among younger adults, objects from visual pairs ($M = .04$) were reliably more likely to be attributed to the wrong source than were objects from control pairs ($M = .02$), $t(21) = 3.07$, but the effect was small; the effect was much larger among older adults (*M*s = .16 and .07, respectively), $t(31) = 6.76$. The increase in false seen responses to visual–imagined objects over control–imagined objects was nearly three times larger among older ($M = .11$) than younger adults ($M = .04$).

It is not the case that participants simply switched source responses to similar seen and imagined objects (e.g., called *magnifying glass* imagined and *lollipop* seen). If they had, false seen responses to imagined objects would have been more common when a similar seen object was called imagined rather than perceived. We calculated proportion source errors for visual–imagined objects, conditional on whether each object's seen pair member was called perceived or imagined. Only those participants who gave both some perceived and some imagined responses to visual–seen objects were included in the analysis ($n = 22$ older and 4 younger adults). Source errors for imagined objects were actually very low when seen pair members were called imagined ($M = .03$) and significantly higher when seen pair members were correctly called perceived ($M = .20$), $t(25) = 5.15$. In other words, it is when seen objects were called perceived, and not when they were called imagined, that similar imagined objects were likely to be falsely called perceived.

Unlike with many studies, including Henkel et al.'s (1998), there was no main effect of source, whereby imagined objects were more likely to be attributed to perception than vice versa (i.e., the it-had-to-be-you effect; Johnson, Raye, Foley, & Foley, 1981), $F(1, 54) = 0.52$, $MSE = .02$. This may be related to the fact that a perceived response, but not an imagined response, required a further location response. Explicitly requiring the report of specific location information for objects judged seen may have reduced participants' inclination to call imagined objects seen and increased their inclination to call seen objects imagined.

Location memory for seen objects. We analyzed location memory for seen objects by calculating, of the seen objects correctly called seen, the proportion attributed to the correct location. These proportions were submitted to a 2 (age: younger vs. older) × 2 (pair type: visual vs. control) ANOVA. There was a main effect of age, $F(1, 54) = 14.33$, $MSE = .05$; location memory was better for younger ($M = .87$) than older ($M = .70$) adults. There was also an effect of pair type, $F(1, 54) = 20.82$, $MSE = .01$; memory for the location of visual–seen objects ($M = .82$) was better than for control–seen objects ($M = .72$). We find it interesting that old–new recognition and imagined–perceived source memory was worse for visual–seen than control–seen objects, suggesting that location memory does not simply reflect old–new and/or imagined–perceived memory.

Location importing. There were four locations in which seen objects appeared, thus chance alone predicts that, when falsely remembered as seen, one in four imagined objects (.25) would be attributed to the location congruent with that of the object's seen pair member. For control–imagined objects that were falsely called seen across all participants, we calculated the proportion attributed to the location of the object's arbitrarily chosen seen pair member. The proportion of congruent attributions was .18 ($n = 5/28$), which does not differ significantly from the chance prediction of .25, $\chi^2(1) = 0.76$. In contrast, for visual–imagined objects that were called seen, the proportion of attributions congruent with similar pair members was .59 ($n = 10/17$) for younger participants and .56 ($n = 46/82$) for older participants; both proportions are significantly greater than chance predicts, smallest $\chi^2(1) = 10.37$. Thus, among both younger and older adults, false memories of imagined objects imported location from memories of similar seen objects.

Were the false memories of younger participants more likely than those of older participants to import location from similar objects? For the eight younger participants who gave one or more perceived responses to visual–imagined objects, the mean proportion of congruent attributions for visual–imagined objects per

Table 2
Mean Proportion Imagined–Perceived Source Errors (With Standard Errors) as a Function of Age, Source, and Pair Type in Experiment 1

Age and source	Pair type: Visual	Control	*M*
Younger			
Imagined	.04 (.01)	.00 (.00)	.02
Seen	.04 (.02)	.03 (.01)	.04
M	.04	.02	
Older			
Imagined	.16 (.01)	.05 (.01)	.11
Seen	.15 (.03)	.08 (.02)	.12
M	.16	.07	

participant was .63, and for the 27 older participants who did the same, it was .54. However, comparing congruent location importing in younger and older participants is complicated by the fact that we could observe location importing in only the small proportion (.33) of younger participants who had false memories for visual–imagined objects.[2] To obtain further evidence that age-related binding deficits limit the importation of features from specific memories of similar perceived events into false memories, we looked separately at older adults below (young-old, $n = 11$) and above (old-old, $n = 13$) our sample's median age of 79.0 who gave one or more false seen responses to visual–imagined objects.[3] The proportion of congruent attributions for false memories of visual–imagined objects was .69 ($n = 22/32$) for young-old participants and .48 ($n = 22/46$) for old-old participants. Both proportions are significantly greater than .25, smallest $\chi^2(1) = 12.78$, but the proportion of congruent attributions per participant was reliably greater for young-old ($M = .70$) than old-old ($M = .42$) participants, $t(22) = 2.17$. Consistent with the proposal that reduced congruent location importing in old-old versus young-old participants was due to reduced location memory for seen objects, these same old-old participants had lower location memory for seen objects ($M = .51$) than did the young-old participants ($M = .69$), $t(22) = 2.11$.

Imagined–perceived source errors in young-old versus old-old participants. Although importing congruent location information into false memories was significantly less common in old-old than young-old participants, imagined–perceived source memory was not different in the two age groups. Repeating the earlier analysis of imagined–perceived source errors on data from all young-old ($n = 14$) and old-old ($n = 15$) participants, there was only a significant main effect of pair type, $F(1, 27) = 40.53$, $MSE = .01$. Source errors were more common for objects from visual pairs ($M = .16$) than control pairs ($M = .06$).

Discussion

In Experiment 1, we observed an age-related deficit in binding seen objects with their location. Location memory was reduced, not only between college-age participants and participants who were 60 or older, but also between the youngest (60–78 years) and the oldest (80–93 years) of the older participants. This result is consistent with the finding that cognitive decline continues throughout the entire life span (Lawrence, Myerson, & Hale, 1998; Park et al., 2002). Differences in location memory were associated with a change in the content of false memories: the false memories of old-old participants were less likely than those of young-old participants to include location information imported from memories of similar seen objects.

Old-old participants were less likely to import the location of similar seen objects, yet (along with young-old participants) they showed a greater increase in false seen responses to similar over control-imagined objects compared with college-age adults. Presumably, regardless of age, testing imagined objects caused shape features of similar seen objects to become activated. However, with increased age, shape features were less tightly bound to other features, including conceptual and location features, and as such, those other features were less likely to become activated along with shape. Therefore, older adults were more likely to falsely remember imagined objects as seen, because perceived shape information was activated in the absence of conceptual information, but were less likely to import location along with shape. Thus, aging may increase the importation of certain feature types (i.e., those that become activated because they are similar to the features of a test event) but reduce the importation of others (i.e., those whose activation relies on being bound to similar features).

Although we were primarily concerned here with memory for imagined objects, note that similarity between seen and imagined objects impaired imagined–perceived source memory equally for both object types. In other words, imagining a similar object increased imagined responses to seen objects, and although this was true for both younger and older participants, the effect was greater for older adults. In previous investigations with identical or similar stimuli but different procedures, similarity to an imagined object has had variable effects on source judgments about seen objects, sometimes increasing source errors (Henkel & Franklin, 1998, Experiment 2; Lyle & Johnson, 2006, Experiment 2) and sometimes having no effect (Henkel & Franklin, 1998, Experiment 1; Lyle & Johnson, 2006, Experiment 1A). Discussion of the variable effect of similarity on source judgments for seen objects is withheld until after the results of Experiment 2 are reported, because in that experiment, similarity actually increased correct perceived responses to seen objects.

Although age differences in Experiment 1 may reflect reduced feature binding with age, another potential factor in source deficits is suggested by Koutstaal (2003) and Mitchell, Johnson, Raye, Mather, & D'Esposito (2000), who proposed that even if older adults have encoded feature information as well as younger adults, they may have greater difficulty using it deliberately on explicit tests of memory (e.g., retrieving or evaluating it). Thus, one interpretation of our results is that age did not affect the degree to which location information was bound to seen objects, but rather affected how effectively that information could be used to make location attributions. From this perspective, our finding that old-old participants were both less likely to remember the location of seen objects and less likely to import perceived location into false memories of imagined objects could indicate an age-related reduction in the deliberate use of feature information activated in either correct or incorrect contexts. This is a plausible interpretation, but we show next, in Experiment 2, that it is possible to obtain a difference in congruent location importing between two groups of college-age participants, whose members presumably did not differ in their ability to deliberately use feature information in memory judgments but did differ in their likelihood (under different experimental conditions) of feature binding. This cannot rule out the possibility that retrieval-based factors contributed to the age-related difference in conjunction memory observed in Experiment

[2] The proportion of younger participants who gave one or more perceived responses to visual–imagined objects in Lyle and Johnson (2006, Experiment 1) was .96. The proportion was smaller in the present experiment, presumably because the retention interval was only 15 min, versus 48 hr in the earlier experiment.

[3] Young-old and old-old participants also were statistically equivalent on self-reported physical well-being and number of medications taken. Young-old adults' Mini-Mental State Examination scores ($M = 29.4$) were significantly higher than those of old-old adults ($M = 28.1$), $t(20) = 2.38$ (equal variances not assumed), but the mean score for old-old adults was within the range of normal cognitive functioning.

1, but it suggests that differences in retrieval processes are not necessary to produce this pattern of results.

Experiment 2

If participants who are less likely to bind together the details of perceived events are less likely to import those details into false memories, then congruent importing should be reduced, even among college-age adults, in a condition that is not favorable to feature binding. To test this prediction, in Experiment 2, we tested two groups of college-age participants in conditions that differed in the opportunity they afforded for feature binding. In one condition, trials in the initial slide sequence lasted only 1 s, and in the other, they lasted 4 s. (By comparison, trial duration in Experiment 1 was 7 s for all participants.) We expected lower location memory for seen objects in the 1-s versus the 4-s condition, reflecting the reduced opportunity for binding object and location in the former versus the latter condition. As a consequence, we furthermore expected less evidence of the importation of congruent location information into false memories in the 1-s versus the 4-s condition. In Experiment 2, we administered the source memory test 48 hr after the slide sequence, instead of 15 min as in Experiment 1, in order to obtain a higher incidence of false memories and thereby assess with more confidence our prediction about the content of false memories.

Method

Participants. Thirty-two Yale University students (21 women, 11 men; mean age = 21.0 years, SD = 3.40 years; median age = 20, range = 18–34 years) participated in return for money or credit in an introductory psychology course.

Materials and procedure. The materials and procedure were identical to those in Experiment 1, with the following exceptions. There were only 16 visual and 16 control pairs in the slide sequence, instead of 20 of both types, resulting in only 32 perception and 32 imagination trials, instead of 40 of both. Participants were given a slightly different orienting task to account for the fact that participants had less time to make the response. On perception trials, participants stated whether the picture on the screen would take more or less than 10 s to draw and, on imagination trials, stated whether the picture they imagined would take more or less than 10 s to draw.

A random half of the participants were assigned to the condition in which trials lasted 1 s, and the other half were assigned to the condition in which trials lasted 4 s. In both conditions, there was a 1-s interstimulus interval.

After the slide sequence, participants were dismissed from the lab and asked to return in 48 hr. The surprise source memory test administered to participants upon their return consisted of the names of the 32 seen and 32 imagined objects from the slide sequence plus 32 new objects. Pair members from visual and control pairs were tested at least 11 trials apart. The order in which pair members were tested was counterbalanced such that each object was tested before and after its pair member for an equal number of participants.

Results

Recognition memory, imagined–perceived source errors, and location memory for seen objects were analyzed in the same manner as in Experiment 1, except that the between-participants manipulation of age was replaced with trial duration (i.e., 4 s vs. 1 s).

Recognition memory. Table 3 shows the mean proportion of objects correctly recognized as old minus the proportion of new objects called old. There was a significant main effect of trial duration, whereby participants in the 4-s condition had higher recognition memory (M = .60) than did those in the 1-s condition (M = .44), $F(1, 30) = 9.52$, $MSE = .09$. The difference in recognition scores was driven mainly by a lower hit rate for participants in the 1-s condition, because the proportion of new objects falsely identified as old was about the same in the 4-s (M = .20) and the 1-s conditions (M = .19), $t(30) = 0.15$. In both the 4-s and the 1-s conditions, about half of the falsely recognized objects were attributed to perception (Ms = .54 and .45, respectively) and half to imagination (Ms = .46 and .55, respectively).

The analysis of recognition memory also yielded a significant main effect of source, such that recognition memory was higher for imagined objects (M = .63) than seen objects (M = .42), $F(1, 30) = 82.00$, $MSE = .02$.

Imagined–perceived source errors. Table 4 shows, of the objects correctly recognized as old, the mean proportion of objects attributed to the incorrect source. There was a significant main effect of trial duration, $F(1, 30) = 4.78$, $MSE = .08$. Participants in the 4-s condition made fewer source errors (M = .23) than did participants in the 1-s condition (M = .31).

There was also a significant interaction between source and pair type, $F(1, 30) = 17.68$, $MSE = .02$. More visual–imagined objects (M = .30) than control–imagined objects (M = .22) were falsely remembered as seen, $t(31) = 3.19$. Conversely, source errors for visual–seen objects (M = .23) were less common than for control–seen objects (M = .34), $t(31) = 2.84$. Trial duration did not interact significantly with source and pair type, meaning that the effect of similarity on imagined–perceived source memory was about the same regardless of whether trials lasted 4 s or 1 s.

Location memory for seen objects. The only significant effect was a main effect of trial duration, such that of the seen objects called seen, a greater proportion were attributed to the correct location in the 4-s condition (M = .59) than the 1-s condition (M = .42), $F(1, 30) = 6.73$, $MSE = .06$.

Location importing. Of the visual–imagined objects called seen by participants in the 4-s condition, .40 (n = 21/53) were attributed to the location of a seen pair member, which is significantly more than the .25 predicted by chance, $\chi^2(1) = 6.04$. In contrast, in the 1-s condition, the proportion of visual–imagined

Table 3
Mean Proportion Correct Recognition (With Standard Errors) as a Function of Trial Duration, Source, and Pair Type in Experiment 2

	Pair type		
Trial duration	Visual	Control	M
4 s			
Imagined	.72 (.04)	.72 (.04)	.72
Seen	.51 (.04)	.46 (.05)	.49
M	.62	.59	
1 s			
Imagined	.52 (.05)	.57 (.05)	.55
Seen	.32 (.05)	.34 (.05)	.33
M	.42	.46	

Table 4
Mean Proportion Imagined–Perceived Source Errors (With Standard Errors) as a Function of Trial Duration, Source, and Pair Type in Experiment 2

Trial duration	Pair type: Visual	Pair type: Control	*M*
4 seconds			
Imagined	.23 (.04)	.16 (.04)	.20
Seen	.23 (.05)	.30 (.05)	.27
M	.23	.23	
1 second			
Imagined	.37 (.04)	.28 (.05)	.33
Seen	.22 (.04)	.37 (.06)	.30
M	.30	.33	

objects called seen that were attributed congruently was only .27 (n = 18/67), which is not reliably greater than .25, $\chi^2(1) = 0.12$. For the 15 of 16 participants in the 4-s condition who gave one or more perceived responses to visual–imagined objects, the mean proportion of congruent attributions per participant was .43; for the 16 participants who did the same in the 1-s condition, the mean was .28. Thus, there was no evidence of congruent location importing in the 1-s condition. As in Experiment 1, the proportion of control–imagined objects called seen that were attributed to the location of an arbitrarily chosen seen pair member (.27, n = 25/92) was not reliably different from .25, $\chi^2(1) = 0.23$.

Discussion

As expected, given that college-age participants accurately remembered seeing an object, they were less likely to remember the object's location when the object had been presented for 1 s versus 4 s. Furthermore, when imagined objects were falsely remembered as seen, there was a typical congruent-location-importing effect in the 4-s condition, but this effect was eliminated in the shorter, 1-s condition.

Seeing a similar object increased false seen responses to imagined objects in both the 1-s and the 4-s conditions, mirroring the increase found in prior experiments in which objects were presented for 7 s (e.g., Experiment 1; Henkel & Franklin, 1998; Lyle & Johnson, 2006). The magnitude of the increase did not differ reliably between the 1-s and the 4-s conditions, despite the fact that there was no evidence of importing perceived location in the 1-s condition. This is consistent with our argument made in reference to Experiment 1 that imagined–perceived judgments were based primarily on the quality and quantity of shape information (and not location information).

Unlike in previous investigations, it was also the case that imagining a similar object, whether for 1 s or 4 s, increased correct seen responses to seen objects. The effect of imagining similar objects on imagined–perceived source memory for seen objects is discussed further below.

General Discussion

The present experiments, along with previous ones (Lyle & Johnson, 2006), show that false memories can acquire content via the inadvertent activation and misattribution (or importation), not only of features that actual events share with false events, but also of additional features that happen to be bound to the shared features, such as location. That is, memories can be specific but false (Johnson & Raye, 1981). Although feature-binding deficits in memory have been implicated in older adults' increased susceptibility to false memories for events that share features with actually perceived events (Henkel et al., 1998; Koutstaal, Schacter, & Brenner, 2001), their possible effects on the content of the resultant false memories has received relatively little attention (but see Gallo & Roediger, 2003). Because features of complex events are less likely to be tightly bound together in the memories of older relative to younger adults, older adults' false memories may import a smaller variety of features from any particular similar event than do younger adults' false memories.

At the same time, binding deficits presumably would make it difficult for older adults to differentiate the source of similar information from multiple complex events, because the similar information would be less tightly bound to information that distinguishes between similar but distinct events. This predicts that had visual–imagined objects been similar in shape to multiple seen objects in Experiment 1, older adults' false memories might have imported shape information from a wider range of seen objects but fewer additional features from any particular similar event.

Thus, although it is useful to conceive of age-related increases in similarity-based false memories as occurring because older adults are less likely to retrieve information (e.g., in this procedure, conceptual information) about events that differentiates them from other similar events (see, e.g., Jennings & Jacoby, 1997; Koutstaal, Schacter, & Brenner, 2001, for discussions), the results of Experiment 1 and Henkel et al. (1998) point to the specificity of the information (e.g., shape and, to a lesser extent, location) about actual events that potentially might come back to older adults, as well as younger adults, as part of their false memories.

We have found among younger adults that false feature information that is imported from memories of perceived events is more vivid and confidently held than information that presumably was internally generated (Lyle & Johnson, 2006); hence, it would seem important to consider the source of feature information (e.g., perceived or imagined) in older adults' false memories and not only its presence or absence. Generally speaking, the relative vividness of particular types of feature information in older adults' false memories should depend on the relative amount of perceived and imagined information that they imported. Several studies have failed to find differences in the phenomenological experience of false memories in younger and older adults using Remember-Know ratings (Tulving, 1985; see also Intons-Peterson, Rocchi, West, McLellan, & Hackney, 1999; Norman & Schacter, 1997) and versions of the memory characteristics questionnaire (Johnson, Foley, Suengas, & Raye, 1988; see Gallo & Roediger, 2003; Henkel et al., 1998; Karpel, Hoyer, & Toglia, 2001; Norman & Schacter, 1997; see also Schacter, Koutstaal, Johnson, Gross, & Angell, 1997), but Remember-Know ratings index only the presence or absence of episodic content, and moreover, those studies were not designed to produce differences in the amount of perceived information in false memories.

If, as we have argued, specific information derived from perceived events becomes activated upon test of similar imagined events, then it presumably is at least as likely to become activated upon test of the perceived events themselves. For example, the features of the seen object *magnifying glass* that become activated upon test of the imagined object *lollipop* should be the same features, or a subset thereof, that become activated upon test of *magnifying glass* itself. Consistent with this, false seen responses to imagined objects in Experiment 1 were significantly more likely when similar seen objects were called seen than when they were called imagined. If the remembered features of a seen object were not sufficiently vivid to support a seen response to that object, then we would not necessarily expect the features to increase the likelihood of a seen response to a similar imagined object.[4] Alternatively, if the remembered features were vivid enough to give rise to a seen response to the seen object, then they might also lead to a seen response to a similar imagined object. In other words, the same features can be used to attribute an event to the correct source and to misattribute an event to an incorrect source depending on the mental context in which the features become activated.

It is of note that imagining a similar object increased false imagined responses to seen objects in Experiment 1 and also increased correct seen responses to seen objects in Experiment 2. One possibility, consistent with the SMF, is that internally generated shape information, in and of itself, tended to increase seen responses to similarly shaped seen objects in both experiments, because it added to the total amount of remembered shape information that was consistent with the seen objects. However, memory for the cognitive operations (i.e., mental effort) involved in generating the shape information should suggest that the seen object was imagined (Finke, Johnson, & Shyi, 1988; Johnson et al., 1981). At the relatively short retention interval of 15 min used in Experiment 1, cognitive operations should be relatively available, and to the extent that such information was misattributed to seen objects, that would explain why imagining a similar object increased imagined responses to seen objects. In contrast, memory for cognitive operations may have been poorer in Experiment 2 than in Experiment 1 because of the briefer imagination trials (1 s or 4 s vs. 7 s) and the longer retention interval (48 hr vs. 15 min). That is, relative to Experiment 1, in Experiment 2 fewer cognitive operations may have been engaged in imagination trials initially and/or they may have been more likely to have been forgotten.

The activation of cognitive operations from imagined events upon test of similar seen objects also may have contributed to the two unexpected effects we obtained in Experiment 1, whereby old-new recognition was lower and location memory was higher for visual–seen than control–seen objects. The activation of cognitive operations in response to test probes for seen objects may have given rise to a phenomenal experience that was difficult to classify as resulting from either prior perception or imagination. Hence, participants sometimes may have called visual–seen objects new to avoid having to make a choice between the two old sources. From this perspective, higher location accuracy for visual–seen objects might be due to the fact that participants withheld seen responses to those objects unless they had a strong sense of location that would indicate perception over imagination.

In Experiment 1, similarity to an imagined object disrupted imagined–perceived source memory for seen objects more for older than younger participants. This suggests that age-related binding deficits may increase the misattribution of cognitive operations from imagined events to similar perceived events, just as they increase the misattribution of shape information from perceived events to similar imagined events.

Finally, concerning the neural basis of binding deficits in older adults, it has been proposed that normal aging disrupts a frontal-hippocampal circuit in which regions of prefrontal cortex maintain the activation of multiple features and the hippocampus binds together coactive features (Mitchell, Johnson, Raye, Mather, & D'Esposito, 2000). Indirect evidence of the relationship between these regions and age-related binding deficits has been reported in the form of correlations between performance on neuropsychological tests believed to recruit these regions and accuracy on a source memory task like the one used in the present experiments (Henkel et al., 1998; see also Glisky, Polster, & Routhieaux, 1995; Glisky, Rubin, & Davidson, 2001). In addition, Mitchell, Johnson, Raye, and D'Esposito (2000) used an fMRI procedure and found that older adults performed worse than younger adults on a working memory task that required feature binding and, unlike younger adults, did not show increased activity in prefrontal cortex and anterior hippocampus on trials that required feature binding compared with those that did not. In their study, unlike in the present one, participants were instructed to bind features, and they maintained combinations of features for several seconds in working memory. Although future research is needed to explicate the locus (or loci) of neuropathology underlying older adults' impairment on long-term source-memory tasks involving incidental binding, the prefrontal cortex and hippocampus are good candidates given the available evidence. The conditions remain to be specified under which such binding deficits increase false memories, because features are more likely to become activated without bound information to help identify events they are coming from, versus decrease false memories, because these activated features are themselves less likely to activate additional features that might be misattributed.

[4] Of course, imagined shape information and weak perceived shape information could combine to constitute a memory that was, in total, sufficiently vivid to produce a seen response to an imagined object.

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