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Autobiographical memory conjunction errors in younger and older adults: Evidence for a role of inhibitory ability

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Abstract

Because of its reconstructive nature, autobiographical memory (AM) is subject to a range of distortions. One distortion involves the erroneous incorporation of features from one episodic memory into another, forming what are known as memory conjunction errors. Healthy aging has been associated with an enhanced susceptibility to conjunction errors for laboratory stimuli, yet it is unclear whether these findings translate to the autobiographical domain. We investigated the impact of aging on vulnerability to AM conjunction errors, and explored potential cognitive processes underlying the formation of these errors. An imagination recombination paradigm was used to elicit AM conjunction errors in young and older adults. Participants also completed a battery of neuropsychological tests targeting relational memory and inhibition ability. Consistent with findings using laboratory stimuli, older adults were more susceptible to AM conjunction errors than younger adults. However, older adults were not differentially vulnerable to the inflating effects of imagination. Individual variation in AM conjunction error vulnerability was attributable to inhibitory capacity. An inability to suppress the cumulative familiarity of individual AM details appears to contribute to the heightened formation of AM conjunction errors with age.

Keywords

Autobiographical memory; False memory; Imagination; Aging; Inhibition

Introduction

Episodic memory representations are stored as constituent features distributed widely across the brain, meaning that retrieval of a coherent episode requires these fragments to be relocated, reactivated and reintegrated (Bartlett, 1932; Schacter, Norman, & Koutstaal, 1998). This flexible memory system is generally advantageous (Schacter, Guerin, & St Jacques, 2011), in that it allows us to recombine details to imagine the future (Schacter & Addis, 2007), creatively solve problems (Howe, Garner, Charlesworth, & Knott, 2011; Madore, Addis, & Schacter, 2015), and update memories with recently acquired information (Lee, 2009; St Jacques, Olm, & Schacter, 2013). However, the downside to this constructive

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setup is that it renders us vulnerable to memory distortions. For instance, erroneous incorporation of features from one memory into another forms what are known as memory conjunction errors. Such errors have previously been shown to occur in autobiographical memory (AM; Burt, Kemp, & Conway, 2004; Devitt, Monk-Fromont, Schacter, & Addis, 2016; Odegard & Lampinen, 2004).

Healthy aging is accompanied by an increased susceptibility to false memory formation (e.g., Jacoby & Rhodes, 2006; Mitchell & Johnson, 2009; Pierce, Simons, & Schacter, 2003), including memory conjunction errors for words (Castel & Craik, 2003; Jones & Jacoby, 2005; Rubin et al., 1999), faces (Kroll, Knight, Metcalfe, Wolf, & Tulving, 1996), and actor-action pairings (Kersten, Earles, Curtayne, & Lane, 2008; Kersten, Earles, & Upshaw, 2013; Kersten & Earles, 2010). Yet it is unknown whether this age-related increase in memory conjunction error susceptibility translates to the autobiographical domain. Laboratory studies have demonstrated that increasing the distinctiveness of stimuli (for example, by presenting stimuli as pictures instead of words) can reduce age differences in source monitoring (Dodson & Schacter, 2002; Ferguson, Hashtroudi, & Johnson, 1992; Johnson, De Leonardi, Hashtroudi, & Ferguson, 1995). Older adults also selectively remember self-relevant information (Castel, Murayama, Friedman, McGillivray, & Link, 2013; Castel, 2007). Given this evidence, aging may not have as large an influence on conjunction error susceptibility when examining more distinctive and self-relevant forms of memory such as AM (McDonough & Gallo, 2008; though see St-Laurent, Abdi, Burianová, & Grady, 2011). Thus, a central aim of this study is to determine whether conjunction errors derived from AM is heightened in healthy aging.

Despite the distinctive nature of autobiographical stimuli, there are still reasons to believe older adults are more susceptible than younger adults to AM conjunction errors. Several cognitive changes accompanying aging may contribute to an increased vulnerability to conjunction errors, including deficits in feature binding mechanisms (Naveh-Benjamin, 2000) and an overreliance on familiarity (e.g., Jones & Jacoby, 2005). These cognitive changes are likely driven by structural and functional dysfunction in brain areas involved in memory encoding, retrieval, and monitoring, particularly the medial temporal lobes and prefrontal cortex (Kroll et al., 1996; McCabe, Roediger, McDaniel, & Balota, 2009; Parkin, Bindschaedler, Harsent, & Metzler, 1996).

Age-related hippocampal dysfunction is associated with deficits in the formation and retrieval of relations between memory components (Hannula, Tranel, & Cohen, 2006; Mitchell, Johnson, Raye, & D'Esposito, 2000; Naveh-Benjamin, 2000; Old & Naveh-Benjamin, 2008; Pertzov et al., 2013), resulting in poorer feature binding and recollection (Chalfonte & Johnson, 1996; Henkel, Johnson, & De Leonardi, 1998; Kessels, Hobbel, & Postma, 2007; Lyle, Bloise, & Johnson, 2006; Naveh-Benjamin, 2000). As such, older adults are reliant on less accurate familiarity processes when making source decisions (Anderson et al., 2008; Craik & McDowd, 1987; Davidson & Glisky, 2002; Dennis, Bowman, & Peterson, 2014; Giovanello, Kensinger, Wong, & Schacter, 2010; Prull, Dawes, Martin III, Rosenberg, & Light, 2006). Consequently, older adults are less efficient at using recall-to-reject mechanisms to identify familiar lures that are semantic associates of studied items (Gallo, Bell, Beier, & Schacter, 2006), and are more susceptible to false alarms based on familiarity

with the features comprising a conjunction lure (Fandakova, Shing, & Lindenberger, 2013; Jones & Jacoby, 2005). Consistent with this notion, poorer associative binding ability is linked with an increased conjunction error rate in both younger and older adults (Fandakova et al., 2013).

Age-associated recollective reductions also mean that the enhanced phenomenological quality used to tag a memory as veridical (cf. source monitoring framework; Johnson, Hashtroudi, & Lindsay, 1993) may no longer be available or reliable, the result being that authentic memories and imagined events are less distinguishable (Duarte, Graham, & Henson, 2010; Gallo, Korthauer, McDonough, Teshale, & Johnson, 2011; Johnson & Raye, 1981; Karpel, Hower, & Toglia, 2001). Indeed, the neural signatures associated with veridical and false recognition are more similar as we age (Duarte et al., 2010; Gutchess, Ieui, & Federmeier, 2007; see also Dennis et al., 2014). Due to this dedifferentiation between internally- and externally-generated memories, imagination inflation is more prominent with age, whereby false memories are more likely to arise following imagination of a corresponding event (Cohen & Faulkner, 1989; Gerlach, Dornblaser, & Schacter, 2014; Lindner & Davidson, 2014; McDaniel, Lyle, Butler, & Dornburg, 2008; Thomas & Bulevich, 2006; though see Pezdek & Eddy, 2001). We have previously demonstrated imagination inflation for AM conjunction errors in younger adults (Devitt et al., 2016); in the current study we examine whether enhanced inflation is observed in older adults.

Age-related medial temporal dysfunction also contributes to the erroneous binding of features across memory representations (Dodson, Bawa, & Krueger, 2007; Fandakova et al., 2013; Kroll et al., 1996). In addition, the ability to inhibit irrelevant stimuli or internally-generated signals is particularly important for accurate memory encoding and retrieval (e.g., Balota et al., 1999, 2000; Budson et al., 2002; Plancher et al., 2009). Reduced inhibition associated with age-related prefrontal changes may mean less efficient suppression of signals derived from the spreading activation of related memory traces (Biss, Campbell, & Hasher, 2013; Campbell, Hasher, & Thomas, 2010; Campbell, Trelle, & Hasher, 2014; Gazzaley, Cooney, Rissman, & D'Esposito, 2005; Hasher, Zacks, & May, 1999). Therefore the tendency to over-bind activated elements pertaining to separate memory traces is magnified (Fandakova et al., 2013; Henkel et al., 1998; Lyle et al., 2006; Lyle & Johnson, 2006). This disinhibition in feature binding could give rise to conjunction errors experienced with a sense of recollection and a high degree of confidence (Dodson, Bawa, & Krueger, 2007; Dodson, Bawa, & Slotnick, 2007; Kroll et al., 1996). Indeed, measures of executive functioning are linked with susceptibility to conjunction errors for laboratory stimuli in older adults (Fandakova et al., 2013; Rubin et al., 1999). Reduced inhibition can also lower suppression of familiarity garnered by the individual memory features comprising a conjunction lure, which may be misattributed as an indicator of event authenticity (Jones & Jacoby, 2001).

Although reduced relational and executive processes are typical in older adults, cognitive aging is a heterogeneous process (Hultsch, Strauss, Hunter, & MacDonald, 2008; Van Petten, 2004), and it is clear that increased susceptibility to false memories is not a universal and inevitable feature of aging (e.g., Intons-Peterson, Rocchi, West, McLellan, & Hackney, 1999; Umanath & Marsh, 2012). Individual variation in cognitive function likely plays a

large role in susceptibility to memory errors, with higher-functioning older adults compensating for specific neurocognitive declines by recruiting additional neural resources, particularly prefrontal areas (Berlingeri, Danelli, Bottini, Sberna, & Paulesu, 2013; Cabeza, Anderson, Locantore, & McIntosh, 2002; Cabeza, 2002; Grady, McIntosh, & Craik, 2003, 2005; Gutchess et al., 2005; Maguire & Frith, 2003; Park & Reuter-Lorenz, 2009; Reuter-Lorenz & Cappell, 2008; Rosen et al., 2002).

In line with this idea, older adults who perform at a high level on neuropsychological tests sensitive to medial temporal and prefrontal functioning are no more vulnerable to false memories than younger adults (Butler, McDaniel, Dornburg, Price, & Roediger, 2004; Chan & McDermott, 2007; Fandakova et al., 2013; Glisky, Rubin, & Davidson, 2001; Henkel et al., 1998; McCabe et al., 2009; Rubin et al., 1999; Thomas & McDaniel, 2013). Moreover, individual differences in false memory susceptibility in healthy younger adults are also linked with variation in performance on neuropsychological tests of episodic memory (e.g., Fandakova et al., 2013; Zhu et al., 2010; though see Lepage, Brodeur, & Bourgooin, 2003; McCabe et al., 2009) and executive functioning ability (Chan & McDermott, 2007; Fandakova et al., 2013; Glisky, Polster, & Routhieaux, 1995; McCabe et al., 2009; Plancher et al., 2009; Rhodes & Kelley, 2005). However, the contribution of relational and executive memory processes to memory distortions in *AM* has not been examined in previous research.

The current study

In the current study we evaluate the influence of aging on the formation and retention of conjunction errors in *AM*. Younger and older participants completed an *AM* conjunction error paradigm (Devitt et al., 2016) that involved retrieving *AM*s and identifying key details, imagining novel past events in response to recombinations of these details, and completing a source recognition test for intact and conjunction detail sets. We collected subjective measures of event phenomenology during imagination and retrieval of conjunction events. Additionally, autobiographical interviews (AI; Levine, Svoboda, Hay, Winocur, & Moscovitch, 2002) of authentic and conjunction memories were coded for event content. Participants also completed a neuropsychological battery of tests probing relational memory and inhibition.

We expected older adults to be more susceptible than younger adults to *AM* conjunction lures overall, due to an overreliance on familiarity-based recognition, in association with disinhibition of feature binding. We predicted a heightened vulnerability to *AM* conjunction errors after imagining a conjunction event, compared with a control associative task, particularly when these imaginings were vivid and plausible. Moreover, we hypothesized that if older adults exhibit a dedifferentiation between internally- and externally-derived experiences, imagination inflation should be more prominent in the older group. We also explore the possibility that heterogeneity in conjunction error susceptibility is accountable by individual and age-related differences in relational memory and inhibitory processes vital to episodic memory encoding and retrieval.

Method

Participants

We recruited 30 younger adults and 28 older adults. Data from two younger adults were excluded (both female), one due to task noncompliance in session three, and the other due to abnormalities in a follow-up MRI scan. Data from two older adults were excluded (both female), one due to a history of transient ischemic attack, and the other due to a conjunction error rate more than three standard deviations above the mean, indicating a misunderstanding of session three instructions¹. Therefore data from 28 younger adults (5 male) and 26 older adults (9 male) were included in analyses of sessions one-three. Three younger adults (all female), and one older adult (male), did not complete the neuropsychological testing session, thus data from 25 younger and 25 older adults were included in analyses of neuropsychological data.

Power analyses were conducted using G*Power (Faul, Erdfelder, Lang, & Buchner, 2007) on the basis of published data to establish minimum sample sizes needed to achieve 80% power at $\alpha = .05$. For age differences in conjunction errors (Old & Naveh-Benjamin, 2008), as well as an age by detail type interaction using the AI (Levine et al., 2002), the minimum was 13 participants per group. For a regression including false alarms as the outcome measure and memory and executive measures as predictors (Chan & McDermott, 2007), a minimum of 25 participants per group were needed. Thus our sample sizes satisfy these requirements.

Demographic data are presented in Table 1. All participants were fluent English speakers with no history of learning disabilities, neurological or psychiatric impairments, and had normal or corrected to normal vision. All older adults scored 88 or above on the Addenbrooke's Cognitive Examination-Third Edition, indicating no early signs of dementia. Participants gave informed consent in a manner approved by the University of Auckland Human Participants Ethics Committee, and were compensated with a \$25 supermarket gift certificate for each session completed.

AM Conjunction Error Paradigm

As described in Devitt et al. (2016), the AM conjunction error paradigm involved three sessions, which were modified here for use with older adults. In session one, AM details were collected; in session two, conjunction events were imagined and an associative task completed; in session three, a source test and interview were carried out (see Figure 1). In an additional fourth session, participants completed a battery of neuropsychological tests assessing relational memory and inhibition ability.

Session One: Stimuli collection—Participants recalled 40–50 AMs of events (specific in time and place and lasting no longer than a day) from the past 10 years, which typically took around two hours to complete. For each AM, participants wrote a brief description, and specified a person (other than themselves) who was involved, the location where it occurred,

¹This participant also showed signs of not engaging with the tasks. Removing her from the analyses did not change the pattern of results.

and a salient object that was present. We provided participants with an extensive list of event cues to facilitate retrieval, but memories were not limited to these cues. Although older adults produced slightly fewer memories ($M = 40.81$, $SD = 3.10$) than younger adults ($M = 44.93$, $SD = 2.14$), both groups generated sufficient stimuli for the paradigm. Importantly, the recency of AMs did not differ across the groups ($M_{younger} = 2.84$ years, $SD = 0.99$, $M_{older} = 2.99$ years, $SD = 1.31$; $t(52) = 0.47$, $p = .64$).

Prior to session two, these memories were screened for adherence to the specificity instructions; at least 38 complying memories were required for recombination². We randomly recombined the memory components to form 78 recombined detail sets (conjunction lures), each consisting of a person, place and object, to be used in sessions two and three. Of these, half were partially recombined (with either the person, place or object component altered), and half fully recombined (where the person, place and object were taken from three different memories). Six additional conjunction lures were created for practice trials in sessions two and three.

Session Two: Conjunction lure exposure—Session two took place approximately 1–2 weeks after session one ($M = 10$ days, $SD = 4$), and was two hours in duration. Participants were presented with 60 conjunction lures, split evenly across an imagination and a control associative condition. The order in which participants completed the imagination and associative tasks, as well as the presentation order of person, place and object components, was counterbalanced. Four practice trials were completed to ensure that instructions were understood.

In the imagination condition, participants had 30 seconds for each conjunction lure to silently simulate a novel event occurring within the past 10 years, involving all three memory components. Each imagined scenario was rated by the participant for vividness and plausibility on a 5-point scale (1 = low, 5 = high). These ratings were followed by a written one sentence summary of the imagined event, to verify that a scenario had indeed been generated.

The associative condition was included to disentangle an effect of imagination inflation effect from that of increased retrieval fluency. In this condition participants processed conjunction lures without forming imagined events, by ranking the three components in order of highest to lowest subjective pleasantness (Gaesser, Spreng, McLelland, Addis, & Schacter, 2013). For example, if shown the details “Tracey, Pharmacy, Chocolate” a response might be “I find chocolate more pleasant than Tracey, and Tracey more pleasant than the pharmacy”. Participants completed this task silently, thinking about their decision for 30 seconds. As control ratings for those in the imagination condition, participants rated each pleasantness judgement for difficulty and average pleasantness on a 5-point scale (1 = low, 5 = high), and wrote a sentence indicating the order of pleasantness ranking.

²In Session One, one older adult managed to retrieve only 29 valid memories; for this participant the number of recombinations presented in sessions two and three were reduced (48 and 89 respectively). Removing this participant from the dataset did not alter the overall results, thus they were retained.

While the conjunction lures were experimentally recombined in a way so as to avoid reconstructing a combination matching an authentic detail set from session one, there was the unavoidable possibility that a conjunction lure may have corresponded to a memory from the individual's past that was not reported in session one. To eliminate the possibility of inadvertently classifying a true memory as a conjunction error in such cases, for each conjunction lure participants answered whether an event involving the three details together had actually occurred to them before. An average of 3.41 detail sets ($M = 5.89\%$, $SD = 4.96$) per participant were excluded from subsequent analysis due to a "yes" response to this question. Exclusion of detail recombinations did not differ across imagination and associative conditions ($F(1, 52) = 0.17$, $p = .68$), nor across younger and older adults ($F(1, 52) = 2.05$, $p = .16$).

Session Three: Source memory recognition test and Autobiographical

Interview—The third session was completed approximately one week after session two ($M = 9$ days, $SD = 4$), and took two hours to complete. Following nine practice trials, participants were presented with a total of 116 detail sets, corresponding to authentic memories (38), session two conjunction lures (60), and new conjunction lures that were not presented during session two (18). For each detail set, participants had 5 seconds to make a source judgement, deciding whether they believed the detail set belonged to a real event, a recombination seen in session two (regardless of imagination or associative condition), or a new recombination not previously seen. Button press responses were made for this decision, and were followed by a confidence rating on a 5-point scale (1 = low, 5 = high). The critical trials in this source test were those where the participant incorrectly recognized a conjunction lure as belonging to a real event, indicating an AM conjunction error was made.

Following the source test, an adapted version of the AI was conducted (Addis, Wong, & Schacter, 2008). An average of 12 detail sets were randomly selected based on responses in the source test: 5 correctly-identified real sets (real hits), 5 correctly-identified imagined sets (imagined hits), and all AM conjunction errors ($M = 2.41$, range = 0–7). For each detail set, participants had three minutes to verbally describe what they remembered about the associated event in as much detail as possible while being audio-recorded. Participants then rated the event for vividness, level of emotional response, and personal significance on a 5-point scale (1 = low, 5 = high), indicated what perspective the event was viewed from (first- or third-person), and were asked to again determine the source of the event.

Audio-recordings of event descriptions were later transcribed and scored according to the AI scoring protocol (Addis, Wong, & Schacter, 2008, adapted from Levine et al., 2002). Transcripts were segmented into distinct pieces of information each conveying a unique idea, which were further classified as either internal or external. Internal details were episodic details pertaining directly to the main event, while external details were those not part of, or specific to, the main event being described, such as semantic facts, metacognitive statements or descriptions of episodes outside the main event (for a scoring example, see Levine et al., 2002). Four raters blind to event condition and age group scored the AI transcripts. To establish inter-rater reliability, all raters scored a set of 20 recalled past and imagined future events obtained from a previous study (Addis et al., 2008). These scores were subjected to an intraclass correlation analysis, revealing that reliability across raters

was acceptable (two-way mixed model; standardized Cronbach's α : internal detail score .94; external detail score .86).

Session Four: Neuropsychological testing—Session four took place approximately two months after session three ($M = 57$ days, $SD = 56$), and took two hours to complete.

Three measures of relational memory were used; the selection of these tests was guided by the results of a factor analysis of measures in Glisky et al.'s (1995) neuropsychological test battery. For all memory tests the sum of immediate learning scores were used, because they provided the largest amount of variance in the younger adult group, and captured the ability to form associations between items in memory. These tests were: *California Verbal Learning Test Second Edition (CVLT-II)*; Delis, Kramer, Kaplan, & Ober, 2000, trials 1–5 free recall); *Visual Paired Associates (PA)* and *Verbal PA hard list* (Wechsler Memory Scale Revised; Wechsler, 1987, trials 1–3).

We selected five subtests from the Delis-Kaplan Executive Function System test battery (D-KEFS; Delis et al., 2001) that load onto an inhibition factor (Floyd, Bergeron, Hamilton, & Parra, 2010; Latzman & Markon, 2010; Li et al., 2015). The tests (and measures) were: *Trail Making* (ratio of the time to complete the number-letter switching task with completion time for the numbers-only task, where a lower ratio indicates better performance); *Verbal Fluency Letter* and *Design Fluency Switching* (number of words or figures generated in accordance with the set rules); *Color-Word Interference* (ratio of the time taken to name words in the inhibition condition with completion time for the simple color naming condition, where a lower ratio indicates better performance); and *Tower Test* (total achievement score).

To obtain reliable and stable measures of relational memory and inhibition abilities, raw scores for all neuropsychological tests were converted to z -scores and collapsed across tests to form separate composite scores of memory and inhibition (Glisky & Kong, 2008; Salthouse et al., 2003), whereby a lower score indicates lower functioning (see Table 1).

Statistical analyses

AM conjunction errors were calculated as a percentage of valid conjunction lure trials (valid trials were those given a “no” response to the question “has an event involving all three details occurred to you before?” in session two). The residual errors for conjunction error rates in all conditions (imagined/control/new) were right skewed (skewness < 2.68 , kurtosis < 10.71). A log transform was used to normalize the data (Field, 2009), improving skewness (< 0.79) and kurtosis (> -1.30). For data comparing AM conjunction error rates, all statistical tests reported were computed using the transformed data and were analyzed using parametric tests, while means and standard deviations presented in tables and figures are based on the untransformed data³. Subjective ratings were analyzed using appropriate non-parametric tests. Pairwise comparisons (t -tests and Wilcoxon signed-rank tests) were considered significant if they exceeded the stated Bonferroni threshold (corrected for multiple comparisons).

³Analyses on transformed and untransformed data yielded the same pattern of results, so interpretations based on the raw means accurately reflect the findings derived from the transformed data.

To assess the influence of age and neuropsychological composite scores on memory accuracy and conjunction error rates, path analyses were carried out using Mplus 7.3 (Muthén & Muthén, 2012), with Maximum Likelihood Estimation using 5,000 bootstrapped re-samples. The dependent variable for one model was AM conjunction error rate, and for a second model was overall accuracy rate. Memory and inhibition composite scores were the independent variables of interest. Multiple group modelling was used to determine whether the effects of memory and inhibition on conjunction error rate differed with age. With 25 participants per group, we had over 10 observations for each parameter in our model, satisfying the recommended lower limit for path analysis (Kline, 2011). Diagnostic tests indicated that the models were not unduly biased by multicollinearity, as tolerance statistics for all variables were above the minimum value of .20 as recommended by Menard (1995).

Results

Conjunction error and accuracy rates

Overall, 39 of 54 participants (72.22%) made at least one AM conjunction error during the source test. Participants made, on average, 2.50 ($SD = 2.91$) conjunction errors, equating to 3.49% of the conjunction lures presented in session three ($SD = 4.12$). Older adults were more susceptible to AM conjunction errors than younger adults, making nearly three times more conjunction errors on average ($t(52) = 2.90, p = .005, d = 0.79$; see Table 2 for percentages). Overall, more older than younger adults made conjunction errors (76.92% of older, 67.86% of younger), yet a significant age difference in conjunction error rate still existed when comparing only those individuals who made conjunction errors ($t(37) = 3.44, p = .001, d = 1.10$). Subjective confidence in these errors did not differ across the age groups ($Mdn\ younger = 3.75, older = 3.57, Mann-Whitney\ U = 189.00, p = .98, r = 0.00$).

The degree of recombination (partial/full) and the type of detail altered (person/place/object) did not differentially influence conjunction error rates of older relative to younger adults. Specifically, a 2×2 mixed analysis of variance (ANOVA) tested the influence of age on conjunction error rates for partially and fully recombined lures. A main effect of recombination degree was found, with more conjunction errors for partially recombined ($M = 4.67\%, SD = 5.44$) compared with fully recombined lures ($M = 2.36\%, SD = 3.63; F(1, 52) = 15.69, p < .001, \eta^2_p = .23$), replicating previous findings (Devitt et al., 2016). No interaction of recombination degree with age was found ($F(1, 52) = 0.70, p = .41, \eta^2_p = .01$). A 2×3 mixed ANOVA further revealed no effect of the type of detail altered, or interaction of detail type with age on conjunction error rates (p values $> .39$). Note that for these and all the following ANOVAs examining conjunction error rates, a significant main effect of age on conjunction error rate was found (p values $< .05$).

Accuracy on the source test was examined with a 2×2 mixed ANOVA on the percentage of correctly-identified authentic memories (real hits) and correctly-identified conjunction lures (conjunction hits), with age group as the between-subjects variable (younger/older). This analysis showed that older adults had fewer real hits ($M\ younger = 89.57\%, SD = 9.34; M\ older = 73.73\%, SD = 15.25$) and conjunction hits than younger adults ($M\ younger = 56.79\%, SD = 11.51; M\ older = 45.12\%, SD = 11.78; F(1, 52) = 33.70, p < .001, \eta^2_p = .39$). Both groups had more hits for real memories than conjunction lures ($F(1, 52) = 180.08, p < .$

001, $\eta^2_p = 0.78$). No interaction between age and hit type was observed, demonstrating that age differences in correct identification of conjunction lures was not more pronounced relative to authentic memories ($F(1, 52) = .83, p = .37, \eta^2_p = 0.02$). For younger adults, a negative correlation was observed between overall accuracy (percentage of correctly-identified trials) and conjunction error rate ($r = -.39, 95\%, CI = -.65, -.09, p = .04$). No correlation was evident for the older group ($r = .01, 95\%, CI = -.42, .57, p = .98$), although the slopes did not significantly differ between the age groups ($t(50) = 1.35, p = .18$).

In the follow-up AI, approximately one third of the conjunction errors made in the source test were still considered to originate from an authentic memory, and the associated event was described by the participant ($M = 32.37\%, SD = 33.19$). While older adults maintained fewer conjunction errors during the AI than younger adults, this difference was not significant ($M_{younger} = 40.79\%, SD = 42.39; M_{older} = 24.36\%, SD = 19.03; t(24.70) = 1.55, p = .13, d = 0.42$). There was, however, a trend for older adults to forget more conjunction error events in the AI than younger adults (i.e., to give an “I don’t remember” response rather than describe an event), suggestive of general age-related recall difficulties ($M_{younger} = 13.16\%, SD = 28.64; M_{older} = 32.45\%, SD = 32.80; t(37) = 1.95, p = .06$).

Effect of imagination

A 2×3 mixed ANOVA explored whether exposure to conjunction lures in session two increased errors above the baseline new condition, with age group as the between-subjects variable, and exposure condition as the within-subjects variable (imagination/associative/new). Because recombinations in the new condition could not be screened prior to the source test for those corresponding to unreported authentic events, comparing the uncorrected error rate of the new condition to the corrected error rate of the imagination and associative conditions (i.e., valid trials only) artificially inflates the number of conjunction errors made for new lures. Therefore, the uncorrected conjunction error rates of all conditions (without removal of invalid trials) was used for this comparison. A main effect of condition was found ($F(2, 104) = 13.88, p < .001, \eta^2_p = .21$). Pairwise comparisons revealed that more conjunction errors were made for lures seen in session two than for new lures, regardless of age, consistent with an effect of familiarity due to prior exposure ($M_{imagination\ uncorrected} = 6.92\%, SD = 7.42; M_{associative\ uncorrected} = 4.86\%, SD = 6.52; M_{new} = 2.70\%, SD = 4.95; p < .001$ and $= .004$ respectively). No interaction between age and condition was observed ($F(1, 104) = .39, p = .68, \eta^2_p = .01$).⁴

We then used a 2×2 mixed ANOVA, with age group and exposure condition (imagination/associative), to compare the influence of age on corrected conjunction error rates. Consistent with imagination inflation, more conjunction errors were observed for the imagination condition compared with the associative condition (although this effect was only trending; $F(1, 52) = 3.09, p = .09, \eta^2_p = .06$). Age had no influence on this effect (age x condition interaction $F(1, 52) = 0.70, p = .41, \eta^2_p = .01$; Table 2 and Figure 2).

⁴For completion, we also ran this analysis on the corrected rate of conjunction errors for the imagination and associative control conditions. Again, a main effect of condition was evident ($F(2, 104) = 3.76, p = .03, \eta^2_p = .07$), and pairwise comparisons revealed that, even at the corrected level, more conjunction errors were made in the imagination condition relative to the new condition ($p = .045$).

Phenomenological characteristics of conjunction errors

Subjective ratings of simulation quality during imagination (session two)—A Friedman's ANOVA was run separately for each age group to explore differences in plausibility and vividness ratings made during imagination across the subsequent memory classifications of the source test: imagined hits (correctly-identified imagined trials), misses (imagined trials incorrectly judged as "new") and conjunction errors (imagined events incorrectly judged as "real"). Subjective ratings of imaginations did not appear to strongly influence subsequent memory classification for either age group. For younger adults a main effect of memory condition was found for plausibility ratings ($\chi^2(2) = 7.09, p = .03$). Follow-up Wilcoxon signed-rank tests (Bonferroni-adjusted $\alpha = .017$) indicated that hits were rated as more plausible than misses ($Mdn\ hit = 2.33, Mdn\ miss = 2.00, T = 53.00, p = .002, r = -0.61$), while no difference was found between conjunction errors ($Mdn = 2.67$) and hits or misses ($T < 17.00, p > .16$). For older adults no difference in plausibility ratings was seen across the memory conditions ($Mdn\ hit = 2.90, Mdn\ error = 3.84, Mdn\ miss = 3.21, \chi^2(2) = 2.09, p = .36$). No significant effect of vividness ratings across subsequent memory conditions was evident for either age group (younger adults $Mdn\ hit = 3.33, Mdn\ error = 3.33, Mdn\ miss = 3.20$; older adults $Mdn\ hit = 3.57, Mdn\ error = 3.50, Mdn\ miss = 3.55; \chi^2(2) < 3.49, p > .18$).

Subjective ratings of memory quality during retrieval (session three)—A 2×3 mixed ANOVA explored the influence of age on the proportion of trials viewed from a first-person perspective during the AI across memory type (real hits/imagined hits/conjunction errors). A main effect of memory type on use of a first-person perspective ($F(2, 68) = 4.88, p = .01, \eta^2_p = .13$), as well as a significant interaction between age and memory condition was found ($F(2, 68) = 4.11, p = .02, \eta^2_p = .11$). Pairwise comparisons demonstrate that younger adults were more likely than older adults to view conjunction errors from a first-person perspective ($p = .003$). Furthermore, for younger adults only, conjunction errors were viewed from a first-person perspective more often than imagined hits ($p = .004$; Figure 3).

Differences in vividness, emotion and personal significance ratings during the AI were tested using a series of Friedman's ANOVAs for each rating, with follow-up Wilcoxon signed-rank tests for significant effects (Bonferroni-adjusted $\alpha = .017$). These tests were run separately for each age group, but because the overall pattern of significance did not differ between younger and older adults, collapsed results across age groups are reported here for brevity (see Table 3 for medians). For all three ratings, real hits were rated higher than imagined hits ($T < 3.00, p < .001, r > -0.86$). For vividness and emotion, real hits were rated higher than conjunction errors ($T < 30.50, p < .017, r > -0.55$), and no difference was found between conjunction errors and imagined hits ($T > 39.00, p > .13, r < -0.35$). However, for personal significance, no difference was found between conjunction errors and real ($T > 27.00, p > .02, r < -0.55$), or imagined hits ($T > 20.00, p > .02, r < -0.54$).

Objective scoring of memory quality during retrieval (session three)—Using a 2×3 mixed ANOVA, we examined the influence of age on mean number of internal details generated in the AI according to memory type (real hits/imagined hits/conjunction errors; Table 3). Younger adults generated more internal details than older adults overall ($F(1, 35) =$

7.49, $p = .01$, $\eta^2_p = .18$). A main effect of condition was found ($F(2, 70) = 37.24$, $p < .001$, $\eta^2_p = .52$). Pairwise comparisons showed that descriptions of real hits contained more internal details than imagined hits and AM conjunction errors (p values $< .001$), while conjunction errors contained more details than imagined hits ($p = .01$; Figure 4). Similarly, a 2×3 mixed ANOVA was run for external details (Table 3); main effects of condition ($F(2, 70) = 5.41$, $p = .01$, $\eta^2_p = .13$) and group were found ($F(1, 35) = 6.15$, $p = .02$, $\eta^2_p = .15$), as well as a significant group by condition interaction ($F(2, 70) = 4.57$, $p = .01$, $\eta^2_p = .12$). Pairwise comparisons showed that whereas younger adults generated a similar amount of external details for real hits, conjunction errors and imagined hits (p s $> .26$), older adults generated more external details for real compared with imagined hits ($p < .001$). An age increase in external details was only observed for real hits ($p = .001$); no difference between younger and older adults was evident for conjunction errors or imagined hits (p s $> .13$).

Relational memory and inhibition

We examined the contributions of neuropsychological measures (relational memory and inhibition composite scores) to AM conjunction error rate using multiple group path analyses. Bivariate correlations of variables entered into the path analyses are presented in Table 4. We first estimated all parameters separately but simultaneously for younger and older adults (Table 5 and Figure 5a). The model was saturated (i.e., all possible relationships were estimated, no degrees of freedom remained), meaning model fit could not be determined. Nonetheless, the model revealed that inhibition ability significantly predicted conjunction error rate for younger, but not older adults, while memory ability did not predict conjunction error rate for either age group. To determine whether age influenced the relationship between the neuropsychological composite scores and conjunction error rate, we examined model fit after constraining the factor loadings to be equal across age groups. The model fit was good, using a minimum criterion of a CFI of .97, and a RMSEA of $< .05$ (Schermelleh-Engel, Moosbrugger, & Müller, 2003), $\chi^2(2) = 1.68$, $p = .43$, CFI = 1.00, RMSEA = .00. The model fit did not significantly differ from the first model ($\chi^2(2) = 1.68$, $p = .43$), indicating that the factor loadings did not differ between younger and older adults. In this constrained model, inhibition ability significantly predicted conjunction error rate for both age groups, while memory ability did not (Table 5 and Figure 5b).

We also examined the contributions of memory and inhibition to accuracy of source judgements in session three (assessed as percentage of correctly-identified trials). The first model estimating all parameters separately for younger and older adults was saturated (i.e., all possible relationships were estimated, no degrees of freedom remained), meaning model fit could not be determined. Neither the memory nor inhibition composite scores contributed significantly to source accuracy for either age group (Table 5). To explore the influence of age on these relationships, factor loadings were constrained to be equal across age groups. The model fit was good, and did not significantly differ from the first model ($\chi^2(2) = 0.04$, $p = .98$, CFI = 1.00, RMSEA = .00; $\chi^2(2) = 0.04$, $p = .98$), indicating no difference in factor loadings across age groups. In this constrained model, accuracy was not predicted by either inhibition or memory (Table 5).

Because the path analyses indicated that inhibition predicted AM conjunction error rate, we further determined whether inhibition had a differential influence on error rates across exposure conditions, using a $2 \times 2 \times 3$ mixed ANOVA, with inhibition ability (high/low, as determined by a median split within each age group separately) and age group as the between-subjects factors, and exposure condition (imagined/associative/new) as the within-subjects variable⁵. A main effect of inhibition ability was found, where those with poor inhibition made more conjunction errors overall ($M_{poor} = 4.77\%$, $SD = 4.93$, $M_{good} = 2.50\%$, $SD = 2.78$; $F(1, 46) = 5.46$, $p = .02$, $\eta_p^2 = .11$). The interactions between inhibition, condition and age were not significant ($F < 0.90$, $p > .88$), suggesting that individuals with poor inhibition are more susceptible to AM conjunction errors regardless of condition or age.

Discussion

In the current study we evaluated the influence of healthy aging on susceptibility to conjunction errors in AM. In particular, we were interested in whether older adults were differentially vulnerable to the effects of imagination. To further determine the influence of aging on memory phenomenology, we collected measures of memory quality for authentic, conjunction error and correctly-identified imagined events, using subjective rating scales and objective scoring of autobiographical memories. We also explored the role of relational memory and inhibition ability on AM conjunction error susceptibility, as a means of identifying the cognitive mechanisms underpinning these errors.

A number of our findings are consistent with the notion of an age-related overreliance on familiarity in the absence of recollection when making source decisions for conjunction stimuli. Older adults exhibited an increased susceptibility to AM conjunction errors compared with younger adults, extending similar findings for laboratory conjunction stimuli to that for distinctive and personally-relevant autobiographical events (Castel & Craik, 2003; Jones & Jacoby, 2005; Kersten et al., 2008, 2013; Kersten & Earles, 2010; Kroll et al., 1996; Rubin et al., 1999). However, no differential increase in conjunction errors following imagination was observed for older adults, and age did not influence patterns of subjective and objective memory quality across authentic and conjunction events. While overall, the false acceptance rate of AM conjunction lures was higher for older than younger adults, considerable individual variation in error rates was observed within both age groups, which was accountable by differences in inhibitory ability, but not relational memory.

Aging and conjunction error susceptibility

Older adults were more prone than younger adults to making conjunction errors irrespective of prior exposure or imagination of a lure, suggestive of a general increased vulnerability to conjunction errors. An age-difference was also observed for lures presented in the new condition, which could indicate that the increased rate of conjunction error acceptance with age is simply due to a bias towards responding “real” (Gerlach, Dornblaser, & Schacter, 2014; Huh, Kramer, Gazzaley, & Delis, 2006; see also Kapucu, Rotello, Ready, & Seidl,

⁵Uncorrected rates of the imagined and associative conditions were used to compare against the new condition, for which invalid trials could not be removed prior.

2008; Koutstaal, Schacter, Galluccio, & Stofer, 1999). However, because conjunction stimuli are being used, it is difficult to tease apart a general response bias from an influence of familiarity. While the recombinations of event components in the new condition are novel, the components themselves are familiar, and relying more on a sense of familiarity than explicit recollection to make source judgements may drive a greater tendency to misattribute previously unseen conjunction lures as corresponding to real events (Jones & Jacoby, 2005).

Regardless of age, more conjunction errors were made in the imagination and associative conditions relative to those in the new condition, consistent with a fluency effect (Garry & Wade, 2005; Jacoby & Dallas, 1981; Kurilla, 2011; Sharman, Garry, & Beuke, 2004; Sharman, Manning, & Garry, 2005). Although only a trend, lures for which an event was imagined were more likely to result in conjunction errors than those presented in the associative condition, in line with imagination inflation (Mazzoni & Memon, 2003; Thomas, Bulevich, & Loftus, 2003) and previous results with AM conjunction errors (Devitt et al., 2016). Yet contrary to our hypothesis, both older and younger adults exhibited the same degree of imagination inflation. Moreover, little evidence was found in the subjective and objective measures of memory quality for an age-related dedifferentiation of authentic and conjunction error memories (for corroborating results, see McGinnis & Roberts, 1996).

It is possible that for older adults, increased difficulties in simulating and retaining imagined events may have dampened the expected increase in imagination inflation. Healthy aging is associated with a reduction in the episodic richness of simulations (Addis, Musicaro, Pan, & Schacter, 2010; Addis et al., 2008), therefore older adults may have had difficulty imagining events that were detailed enough to be mistaken as an authentic memory. Previous studies finding an age difference in imagination inflation used relatively simplistic (and easily imaginable) action scenarios (e.g., McDaniel et al., 2008; Thomas & Bulevich, 2006), in which generation difficulty may have had less of an influence. Declines in the ability to retain simulations between the imagination and test phases may also have limited imagination inflation for older adults. Indeed, those older adults scoring below chance on the source test for the imagination condition, indicating poor memory for imagined events, made fewer conjunction errors to imagined lures ($N = 11$; $M = 3.52\%$, $SD = 4.69$) than those above chance ($N=15$; $M = 8.27\%$, $SD = 6.25$, $t(24) = 2.11$, $p = .05$, $d = 0.57$), despite subjective ratings of event quality at the time of imagination being equal. Thus deficits in remembering simulated events over time may have precluded the formation of memory conjunction errors in response to imagination for older adults.

Due to recollective declines, and/or time pressures in the source test, it is also likely that older adults based source decisions on feelings of familiarity rather than the phenomenological characteristics elicited by the lures, accounting for the generalized increase in conjunction error rate across both exposure conditions (Anderson et al., 2008; Craik & McDowd, 1987; Davidson & Glisky, 2002; Dennis et al., 2014; Jacoby, 1999; Jones & Jacoby, 2005; Prull et al., 2006). A reliance on familiarity during source decisions with age is further supported by the fact that older adults maintained fewer AM conjunction errors than younger adults during the AI. Those younger adults who were more accurate at determining source overall also made fewer conjunction errors, consistent with a recall-to-reject mechanism of source monitoring (Jones & Atchley, 2006; Jones & Jacoby, 2005;

Lampinen, Odegard, & Neuschatz, 2004). Such an approach would allow rejection of a conjunction lure by recalling either the authentic detail combinations or the recombined detail sets encountered in session two. Interestingly, no relationship between overall source accuracy and conjunction error susceptibility was evident for older adults, perhaps indicative of an inability to use recall-to-reject processes (Jones & Jacoby, 2005).

The perspective taken during recall also suggests that older adults have difficulty in retrieving recollective information about conjunction errors. Younger adults were more likely to report viewing conjunction errors from a first-person (as opposed to a third-person) perspective than were older adults. Moreover, only younger adults viewed conjunction errors from a first-person perspective more often than imagined hits. Piolino and colleagues (2006) also report decreased use of a first-person perspective with age, and implicate deficits in memory recall to account for this finding; our results suggest this effect may be more pronounced when retrieving events that did not truly take place. Moreover, an age-related decrease in internal episodic information was found, replicating previous findings (Addis et al., 2010, 2008; Gaesser, Sacchetti, Addis, & Schacter, 2011; Levine et al., 2002) and extending these findings to conjunction memories.

Yet the fact that like younger adults, older adults were able to describe and maintain a proportion of the conjunction errors in the AI suggests at least some of these errors are associated with a sense of phenomenological recollection (see also Dijkstra & Misirlisoy, 2009). These recollected errors may occur due to excessive binding of the independent features across memory traces, as poorer associative binding ability has been previously linked with an increased rate of conjunction errors in both younger and older adults (Fandakova et al., 2013). Conjunction errors were rated as intermediate between authentic and imagined hits in personal significance during recall, suggesting that lures that were falsely recognized as real were more personally salient than those that were correctly rejected, and may also have had stronger associations with stored memory traces (Burt et al., 2004; Heaps & Nash, 2001; Johnson et al., 1988). Regardless of age, descriptions of conjunction error events also contained more internal details than correctly-identified imagined events. These findings implicate increases in conjunction error phenomenology in at least some source misattributions, for both younger and older adults (Johnson et al., 1993).

Relational memory and inhibition ability

We investigated whether individual variation in AM conjunction error rates could be accountable by differences in relational memory and inhibitory ability. Older adults were impaired relative to younger adults on composite measures of memory and inhibition ability, consistent with typical age-related declines (Balota et al., 2000; Buckner, 2004; Hedden & Gabrieli, 2004; Hoyer & Verhaeghen, 2006; Moscovitch & Winocur, 1995; Park et al., 2002; Raz et al., 2005; Tisserand et al., 2004; West, 1996).

For younger adults, only inhibition ability predicted the individual AM conjunction error rate, expanding upon similar findings exploring memory distortions for simple laboratory stimuli (Delbecq-Derouesné, Beauvois, & Shallice, 1990; Fandakova et al., 2013; Garoff-Eaton, Kensinger, & Schacter, 2007; Glisky et al., 1995; McCabe et al., 2009; Parkin et al.,

1996; Plancher et al., 2009; Rapcsak, Reminger, Glisky, Kaszniak, & Comer, 1999; Rhodes & Kelley, 2005; Swick & Knight, 1999). The heightened susceptibility to conjunction errors following reductions in inhibition ability may arise due to a difficulty in suppressing the sense of familiarity piqued by the individual components comprising a conjunction lure at retrieval (Arndt & Jones, 2008; Jacoby, 1991; Jones & Jacoby, 2001), compounded by difficulties in recollecting the true source of a lure (Jones & Jacoby, 2005; Leding, 2015). Lowered inhibition ability may also result in deficits in controlling the spreading activation of related – though irrelevant – memory traces, contributing to hyper-binding of disparate memory components (Campbell et al., 2014; Fandakova et al., 2013; Reinitz & Hannigan, 2001). Future research is required to confirm whether one or both of these explanations regarding reduced inhibition are applicable to the formation of AM conjunction errors.

The relationship between inhibition and AM conjunction error rate was not significant when tested on older adults alone, however there was also no difference in this relationship between the age groups, and inhibition remained a significant predictor in the model where group differences were constrained to be equal. Therefore, the results are suggestive of a link between inhibition and conjunction error rates in older as well as younger adults. Previous research points towards a complex relationship between inhibition and memory distortion in older adults (Lövdén, 2003; Sommers & Huff, 2003). Moreover, inhibition is thought to comprise three functions – access, deletion and restraint – which may be reliant on separate mechanisms or neural substrates (Feyereisen & Charlot, 2008; Hasher et al., 1999; Lustig, Hasher, & Zacks, 2007). Accounting for these different aspects of inhibition could provide a clearer picture of the relationship between inhibition and memory distortion in older adults, though a recent attempt at such a fine grained approach did not find an independent contribution of inhibitory functions (Colombel, Tessoulin, Gilet, & Corson, 2016). Future research should disentangle the influence of healthy aging on the role of inhibitory control in memory distortions.

We hypothesized that reductions in relational memory would result in underutilization of recollective strategies and overreliance on familiarity in the source test (Anderson et al., 2008), conferring an increased susceptibility to AM conjunction errors; however, this hypothesis was not borne out. This is not the first report of a lack of relationship between memory functioning and vulnerability to memory distortions (see Balota et al., 1999; Glisky et al., 1995; McCabe et al., 2009). It is possible that the influence of relational memory on AM conjunction error susceptibility is dependent on executive processes. In order to determine whether the influence of memory on AM conjunction error susceptibility was moderated by inhibition ability, we re-ran the path analyses to include a memory by inhibition interaction term. The interaction was not significant, indicating that influence of relational memory abilities on AM conjunction error rates did not differ as a function of inhibition ability for either group ($B_s < -0.50$, $SE_s > 2.99$, $z_s < -0.06$, $p_s > .87$). Perhaps higher-level cognitive resources (such as those regulated by the prefrontal cortex) are required to make fine-grained distinctions between small content changes in complex AMs, as occurs with AM conjunction errors, and thus relational memory may not have had as noticeable an impact on memory distortions of this type. Moreover, in older adults at least, source monitoring deficits attributable to medial temporal lobe-decline may have been

balanced by the recruitment of compensatory frontal mechanisms (see Cabeza, 2002; Grady et al., 2003; Reuter-Lorenz & Cappell, 2008).

Neither relational memory nor inhibitory control were associated with overall source accuracy. It may be that the heterogeneity in the strategies that could be employed to successfully perform the source test masks an influence of these measures on source accuracy. For instance, correct source determination is possible with either a predominately recollective or familiarity strategy: one may explicitly recall a previous experience with the component combination (as self-generated in session one, or presented in session two); alternatively one might rely on familiarity with the detail combination. While a familiarity strategy would inflate rates of false alarms, hit rates would remain fairly comparable as when a recollective strategy is utilized.

Conclusions

In summary, this study adds to the literature of an age-related increase in conjunction errors for simple laboratory stimuli, demonstrating a similar effect for distinctive and personally-relevant AMs. Older adults were not differentially vulnerable to the inflating effects of imagination, suggestive of a generalized susceptibility to conjunction errors with age. Deficits in recollection with increasing age may have necessitated a dependency on error-prone familiarity mechanisms. The findings from the neuropsychological tests reveal that the individual variation in AM conjunction error vulnerability is attributable to declines in inhibitory capabilities, most strongly for younger adults. This lowered inhibition ability may manifest as an inability to suppress the cumulative familiarity of the individual AM components, and the erroneous binding of features due to spreading activation of related memory traces.

These results may have implications for situations in which memory authenticity is of high importance, such as in eyewitness testimony (Loftus, 2003). As many crime cases rely on eyewitness testimony due to a lack of forensic evidence (Zember, Brainerd, Reyna, & Kopko, 2012), it is imperative to an effective justice system to understand the conditions under which memory can become distorted. It has previously been demonstrated that older adults are more likely than young adults to report incorrect information in an eyewitness account (Aizpurua, Garcia-Bojos, & Migueles, 2009; Cohen & Faulkner, 1989). AM conjunction errors can contribute to flawed eyewitness accounts; for instance, spectators can conflate the perpetrator of a crime with innocent bystanders (Buckhout, 1975), a mistake we are more likely to make as we age (Kersten et al., 2008, 2013; Kersten & Earles, 2010). Our results indicate that witnesses with a poor ability to inhibit irrelevant familiarity signals are particularly vulnerable to such errors.

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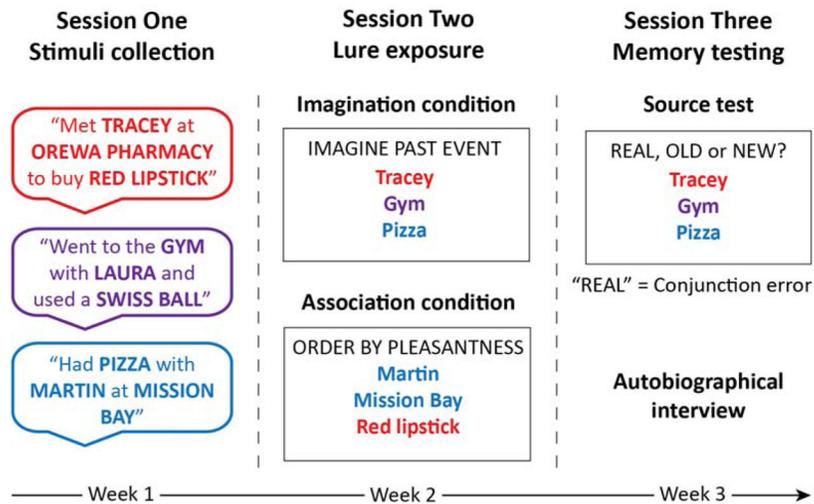


Figure 1. A schematic diagram of the autobiographical memory conjunction error paradigm, depicting example memory components collected during session one, partially and fully recombined detail sets presented in session two, and detail sets presented in the source test of session three. Note colors are used to highlight recombinations; stimuli were presented to participants in black and white.

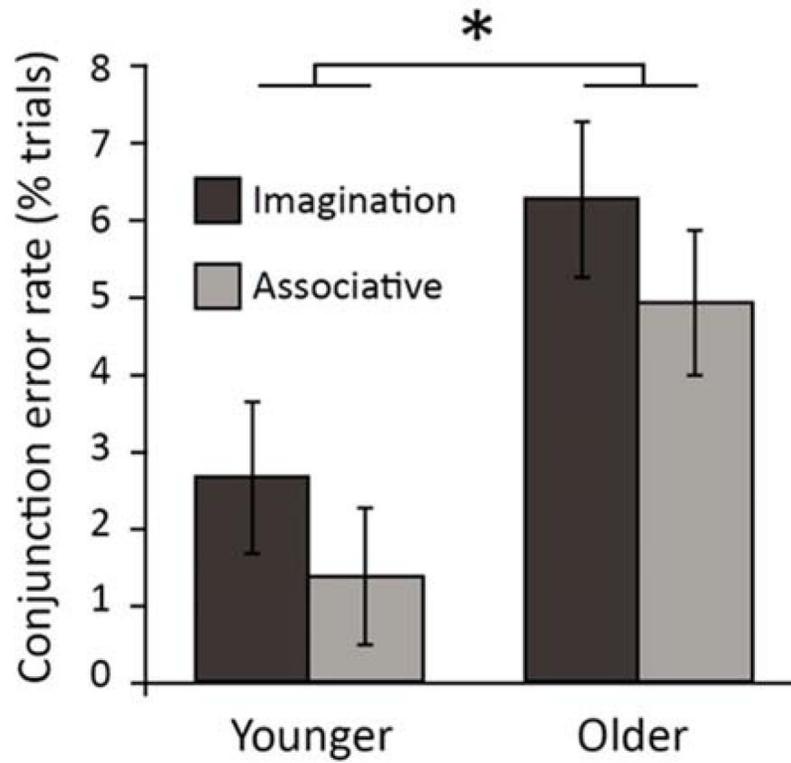


Figure 2. Autobiographical memory conjunction error rates (corrected) for younger and older adults, for conjunction lures presented in the imagination and associative conditions. Error bars reflect standard error of the mean. * = $p < .05$.

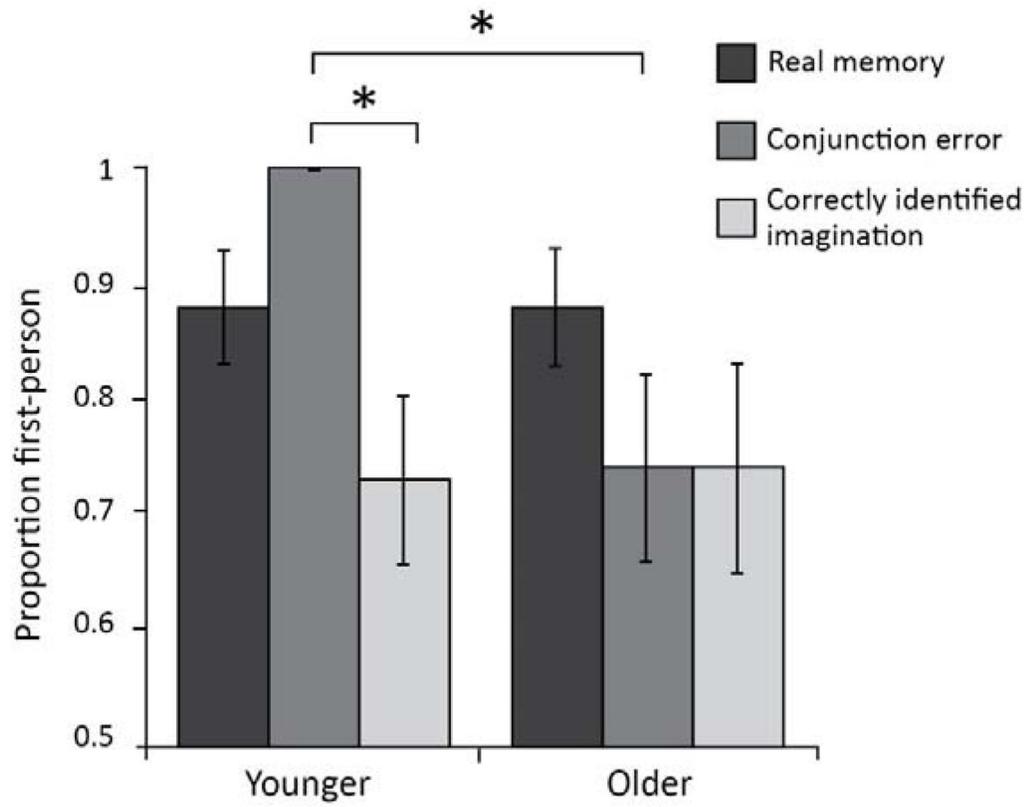


Figure 3. Proportion of events recollected from a first-person perspective for younger and older adults, across memory retrieval type. Error bars reflect standard error of the mean. * = $p < .05$.

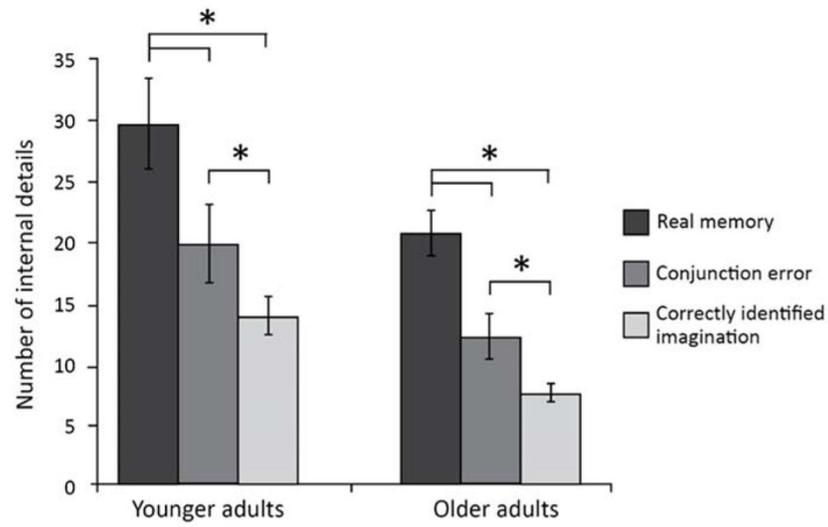


Figure 4. Average number of internal details generated in the adapted Autobiographical Interview for younger and older adults, across memory retrieval type. Error bars represent standard error of the mean. * = $p < .05$.

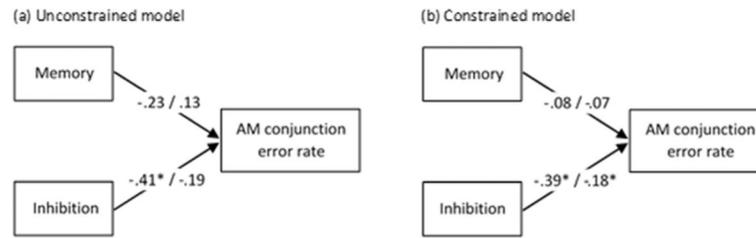


Figure 5. Path analyses predicting autobiographical memory (AM) conjunction error susceptibility. (a) Factor loadings allowed to vary between younger and older adults. (b) Factor loadings constrained to be equal across age groups. The standardized coefficients for younger adults are presented on the left, with those for older adults on the right. * $p < .05$.

Table 1

Mean demographics and neuropsychological test scores.

Measures	Younger adults	Older adults
Participants completing sessions one-three		
Number of participants	28 (5 male)	26 (9 male)
Age (years) *	21.29 (3.54)	71.85 (4.61)
Education (years)	14.95 (1.90)	15.80 (3.35)
ACE-III	--	94.42 (3.35)
Participants completing session four^a		
Number of participants	25 (5 male)	25 (8 male)
Age (years) *	21.44 (3.68)	72.04 (4.60)
Education (years)	14.94 (1.93)	15.86 (3.21)
ACE-III	--	94.64 (3.23)
AM conjunction error rate (% trials) *	2.12 (2.17)	5.24 (5.06)
Memory performance (session four participants)		
CVLT-II: 1–5 free recall total correct *	60.16 (7.10)	48.48 (9.64)
Visual PA: learning sum *	15.04 (2.63)	10.74 (3.43)
Verbal PA: learning sum hard pairs *	9.92 (1.41)	6.25 (3.63)
Memory composite (z-score) *	0.56 (0.38)	-0.63 (0.82)
Inhibition performance (session four participants)		
Trails: ratio number-letter switching to number	2.19 (0.63)	2.5 (0.98)
Verbal fluency: total letter	45.8 (8.45)	41.44 (10.97)
Design fluency: switching *	10.58 (2.75)	7.58 (2.24)
Color-word inhibition: ratio inhibition to color naming *	1.70 (0.29)	1.95 (0.31)
Tower: achievement score	18.88 (3.47)	17.44 (4.59)
Inhibition composite (z-score) *	0.28 (0.43)	-0.29 (0.48)

Note. Standard deviations are provided in parentheses. PA = paired associates, AM = autobiographical memory, ACE-III = Addenbrooke's Cognitive Examination, Third Edition.

* difference between groups is significant at the relevant Bonferroni-corrected threshold (for demographic measures $\alpha = .05$, for memory measures $\alpha = .01$, and for executive functioning measures $\alpha = .008$).

^aNote that all participants in session four also completed sessions one-three.

Table 2

Mean percentage of trials resulting in autobiographical memory conjunction errors for younger and older adults, according to exposure condition.

Exposure Condition	Younger adults	Older adults
Imagination	2.66 (4.19)	6.26 (6.03)
Associative	1.39 (2.20)	4.92 (6.37)
New	1.43 (2.94)	4.07 (6.23)
Total	1.89 (2.12)	5.22 (5.01)

Note. Standard deviations are provided in parentheses.

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Mean and median ratings for subjective phenomenological qualities and objective Autobiographical Interview scores during the retrieval of events in session three.

Table 3

Event type	Phenomenological quality					
	Subjective			Objective		
	Vividness ^a	Emotion ^a	Personal significance ^a	First-person perspective ^b	Internal details	External details
Younger adults						
Real ^c	4.2	3.1	2.3	0.88 (0.21)	29.97 (16.24)	8.67 (5.13)
Conjunction errors	3.83	2.00	1.00	1.00 (0.00)	20.07 (14.14)	11.13 (11.16)
Imagined ^c	3.00	1.73	1.37	0.73 (0.31)	14.02 (7.05)	7.84 (7.96)
Older adults						
Real ^c	4.45	3.50	3.45	0.88 (0.22)	20.96 (7.92)	19.89 (11.95)
Conjunction errors	3.11	2.43	2.49	0.74 (0.35)	12.41 (7.58)	14.72 (10.71)
Imagined ^c	2.5	2.17	2.13	0.74 (0.39)	7.67 (3.19)	11.30 (5.10)

^aMedians, rating scale ranges from 1 (low) to 5 (high).

^bProportion events.

^cCorrectly-identified. Standard deviations are provided in parentheses.

Bivariate correlations for variables entered into path analyses predicting source accuracy and AM conjunction error rate for younger and older adults.

Table 4

	Younger adults				Older adults			
	1	2	3	4	1	2	3	4
1. AM conjunction error rate	–				–			
2. Source accuracy	–.41*	–			–.01	–		
3. Memory composite score	–.19	.04	–		.08	.12	–	
4. Inhibition composite score	–.39	–.10 ⁺	–.08	–	–.16	–.03	.23	–

AM = Autobiographical memory.

* $p < .05$,

⁺ $p < .06$

Table 5
Unstandardized and standardized beta values for the path analyses predicting source accuracy and AM conjunction error rates.

	Younger adults					Older adults					Constrained model				
	<i>B</i>	<i>SE</i>	95% CI	<i>p</i>	<i>R</i> ²	<i>B</i>	<i>SE</i>	95% CI	<i>p</i>	<i>R</i> ²	<i>B</i>	<i>SE</i>	95% CI	<i>p</i>	
AM conjunction error rate				.20					.04						
Memory	-1.29	1.17	-3.43, 0.36	.27	0.78	1.43	-1.27, 3.43	.59			-0.44	0.80	-1.70, 0.90	.58	
Inhibition	-2.07*	0.92	-3.49, -0.48	.03	-2.04	1.66	-4.79, 0.60	.22			-1.93*	0.85	-3.28, -0.53	.02	
Source accuracy				.01				.02							
Memory	0.79	5.26	-6.31, 11.26	.88	1.43	2.40	-2.10, 5.96	.55			1.37	2.12	-1.81, 5.34	.52	
Inhibition	-2.01	4.58	-9.74, 5.11	.66	-1.15	4.46	-7.17, 7.75	.80			-1.48	3.16	-6.13, 4.24	.64	

AM = autobiographical memory.

* $p < .05$