Misrecollection prevents older adults from benefitting from semantic relatedness of the memoranda in associative memory

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Abstract

Memory for episodic associations declines in aging, ostensibly due to decreased recollection abilities. Accordingly, associative unitization - the encoding of associated items as one integrated entity - may potentially attenuate age-related associative deficits by enabling familiarity-based retrieval, which is relatively preserved in aging. To test this hypothesis, we induced bottom-up unitization by manipulating semantic relatedness between memoranda. Twenty-four young and 24 older adults studied pairs of object pictures that were either semantically related or unrelated. Participants subsequently discriminated between intact, recombined and new pairs. We found that semantic relatedness increased the contributions of both familiarity and recollection in young adults, but did not improve older adults' performance. Instead, they showed associative deficits, driven by increased recollection-based false recognition. This may reflect a "misrecollection" phenomenon, in which older adults make more false alarms to recombined pairs with particularly high confidence, due to poorer retrieval monitoring regarding semantically-related associative probes.

Keywords

Episodic memory; semantic memory; unitization; familiarity; aging

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Introduction

Remembering associations between the elements of an event is a critical function of our episodic memory system. Dual-process theories hold that episodic recognition judgments can be supported by two distinct processes: familiarity, representing relatively automatic recognition without retrieval of associated details, and recollection, the controlled retrieval of the information and its associated encoding context (see Yonelinas, 2002; Yonelinas, Aly, Wang, & Koen, 2010; for reviews). While single item recognition memory is supported by both familiarity and recollection, the retrieval of novel episodic associations is thought to be achieved by using recollection only (Hockley & Consoli, 1999). Associative recognition memory is typically tested by requiring discrimination between intact pairs and recombined ones (studied items in new pair combinations). In that way, the items comprising the intact and recombined pairs are equal in episodic familiarity, and only recollection of the associations between items can be relevant to that discrimination.

However, recent research has suggested that unitization—the encoding of associated items as a single integrated entity (Graf & Schacter, 1989) —may allow associative recognition memory to rely on familiarity (Parks & Yonelinas, 2009, 2015; Yonelinas, 2002; Yonelinas, Kroll, Dobbins, & Soltani, 1999). This hypothesis is supported by numerous findings from cognitive behavioral (Ahmad & Hockley, 2014; Diana, Yonelinas, & Ranganath, 2008; Jäger & Mecklinger, 2009; Tibon, Vakil, Goldstein, & Levy, 2012), neuropsychological (Giovanello, Keane, & Verfaellie, 2006; Quamme, Yonelinas, & Norman, 2007), electrophysiological (Bader, Mecklinger, Hoppstädter, & Meyer, 2010; Diana, Van den Boom, Yonelinas, & Ranganath, 2011; Ecker, Zimmer, & Groh-Bordin, 2007; Jäger, Mecklinger, & Kipp, 2006; Kounios, Smith, Yang, Bachman, & D'Esposito, 2001; Opitz & Cornell, 2006; Rhodes & Donaldson, 2007, 2008; Tibon, Gronau, Scheuplein, Mecklinger, & Levy, 2014; Zheng, Li, Xiao, Broster, Jiang, & Xi, 2015), and functional magnetic resonance imaging (fMRI) (Bader, Opitz, Reith, & Mecklinger, 2014; Diana, Yonelinas, & Ranganath, 2010; Ford, Verfaellie, & Giovanello, 2010; Haskins, Yonelinas, Quamme, & Ranganath, 2008; Staresina & Davachi, 2010) studies.

Unitization can be achieved using two types of experimental strategies, driven by either top-down or bottom-up cognitive processes (Tibon et al., 2014). Top-down unitization is induced by explicit encoding instructions which encourage the processing of a newly learned association as a single unit, as opposed to processing items as two separate entities (e.g., compound word definition versus use-in-sentence encoding; Quamme et al., 2007). In contrast, bottom-up unitization is engendered by optimizing existing item features or associative information that could foster unitization. Bottom-up unitization might arise from perceptual or conceptual characteristics of the stimuli. For instance, the visual perception literature has provided evidence for the importance of semantic, spatial, and/or action relations between objects for their online unitization or perceptual grouping (Green & Hummel, 2006; Gronau & Shachar, 2014; Riddoch, Humphreys, Edwards, Baker, & Willson, 2003). Importantly, semantic relatedness between associated items has been shown to enhance the contribution of familiarity to associative recognition memory (Greve, Evans, Graham, & Wilding, 2011; Greve, van Rossum, & Donaldson, 2007; Kriukova, Bridger, & Mecklinger, 2013; Tibon et al., 2014). However, this effect was only recently interpreted

within the framework of unitization by Tibon et al. (2014), who manipulated the "semantic unitizability" of memoranda, that is, the semantic relatedness between pairs of object pictures, and showed that semantic relatedness enhanced the contribution of familiarity (expressed by its event-related potential (ERP) correlate) during recognition of related versus unrelated pairs of objects.

Typically, cognitive aging is accompanied by a decline in episodic memory. It has been suggested that age-related episodic decline stems at least partially from deficits in the encoding and retrieval of associations (associative-deficit hypothesis [ADH]; (Bender, Naveh-Benjamin, & Raz, 2010; Brubaker & Naveh-Benjamin, 2014; Naveh-Benjamin, 2000; Naveh-Benjamin, Brav, & Levy, 2007; Naveh-Benjamin, Hussain, Guez, & Bar-On, 2003; Old & Naveh-Benjamin, 2008). The age-related associative deficit is characterized by relatively preserved memory performance for single items alongside a dramatic decline in memory performance, compared with young adults, in associative memory tests requiring discrimination between intact and recombined pairs. This was shown across a wide variety of materials, including word pairs, face–face, face–name, item–location, and object–color associations (see Old & Naveh-Benjamin, 2008 for a meta-analysis). This difficulty in recognizing episodic associations in older adults is mostly explained by a decline in recollection, contrasted with relatively preserved familiarity (see Davidson & Glisky, 2002 for a review).

However, Naveh-Benjamin et al. (2007) showed that encouraging the use of appropriate associative strategies in older adults, either during encoding alone or during retrieval as well, could induce attenuation of the age-related associative deficit, thereby suggesting that the associative deficit could be due to poor or inappropriate use of strategies (but see Dunlosky & Hertzog, 1998). For instance, a strategy such as unitization, because it promotes familiarity-based associative memory, may provide a means to alleviate older adults' associative deficit. Indeed, several studies indicate an age-related benefit in recognition of unitized associations compared with non-unitized ones, accompanied by a greater reliance on familiarity (bottom-up unitization: Ahmad, Fernandes, & Hockley, 2015; Troyer, D'Souza, Vandermorris, & Murphy, 2011; Zheng, Li, Xiao, Broster, & Jiang, 2015; top-down unitization: Bastin et al., 2013; D'Angelo et al., 2016). Similarly, semantic relatedness or congruence with preexisting schema in semantic memory, which is preserved in aging, has been shown to improve older adults' associative recognition (Badham, Estes, & Maylor, 2012; Badham & Maylor, 2015; Castel, 2005; Naveh-Benjamin et al., 2003; Patterson, Light, Van Ocker, & Olfman, 2009; see Umanath & Marsh, 2014 for a review), possibly via bottom-up unitization as well.

Several studies, however, have failed to observe such age-related benefits of unitization. For instance, using pairs of faces, Jäger, Mecklinger, and Kliegel (2010) demonstrated worse associative memory performance in older adults for unitized compared with non-unitized associations. Using preexisting unitized associations such as compound word pairs, Delhaye and Bastin (2016) also failed to reproduce the age-related associative benefit—although correctly recognized unitized associations were accompanied by enhanced familiarity compared with non-unitized ones—due to a high false alarm rate, seemingly triggered by the absolute familiarity of the distractors. A possible resolution of these seemingly conflicting

results may be suggested by recent studies by Badham, Hay, Foxon, Kaur, and Maylor (2015) and Mohanty, Naveh-Benjamin, and Ratneshwar (2016). They proposed that unitization inherent in semantically familiar materials—such as related word pairs or compound words—can only attenuate the age-related associative deficit when providing additional and unequivocal cues for episodic memory discrimination (a "unique relations" condition in which each association of a study list exhibits a specific relatedness relationship, as opposed to a "shared relations" condition in which multiple associations of a study list are related in the same way; Badham et al., 2015). Otherwise, older adults would face difficulty in differentiating between the relative familiarity of studied associations and absolute familiarity borne by the distractors due to prior knowledge (Delhaye & Bastin, 2016).

Accordingly, the current study aimed at further exploring the effect of aging on associative memory by investigating the impact of prior semantic knowledge engendering bottom-up unitization on episodic recognition. Bottom-up unitization has the advantage of relying to a lesser extent on self-initiated processing, since it depends mainly on bottom-up perceptual processing or on processing of semantic regularities of the to-be-associated components (Bridger et al., 2017). We tested memory for pairs of pictures that were either semantically related or not, under conditions that model ecological perception and memory, using the same materials as Tibon et al. (2014), who found an early mid-frontal ERP familiarity effect for related picture pairs. With this procedure, we assessed whether semantic unitizability of memoranda disproportionately benefitted older adults' associative recognition memory, or rather impaired their discrimination of rearranged but related distractors because of prior knowledge triggering a strong sense of familiarity. Based on Tibon et al.'s (2014) study that found increased familiarity correlates for related pairs as compared to unrelated ones, and because familiarity is typically preserved in aging, our main prediction was that we will observe an age-related benefit of semantic relatedness in associative memory performance. However, it is also possible that the high plausibility of co-occurrence and the absolute familiarity of related distractors would induce more false recognition in aging, preventing older adults from benefitting from semantic relatedness (Gutchess & Park, 2009; Mohanty et al., 2016). Moreover, we used a Remember/Know/Guess paradigm to characterize the processes underlying recognition decisions, predicting that recognition of related object pairs would be accompanied by an overall increase in the use of familiarity compared with unrelated pairs.

Methods

Participants

Twenty-four young (12 females, mean age = 22.8, SD = 2.4 years, range 19–30) and 24 healthy older adults (12 females, mean age = 68.5, SD = 6.9 years, range 60–83) participated in the study. The groups were matched in terms of the number of years of education (mean = 14, SD = 1.6 years for young and mean = 14, SD = 3 years for older adults, which did not differ significantly, $t(46)$ = −0.06; p = 0.95). All participants were right-handed fluent French speakers, had normal or corrected-to-normal vision and hearing, and declared having no history of neurological or psychiatric disorders. None of the older adults evidenced any

sign of cognitive decline (Mattis Dementia Rating Scale; score range: 132–144 out of 144, all within norms, Pedraza et al., 2010). Participants were evaluated on their semantic knowledge using the Mill-Hill vocabulary test (Part B; Deltour, 1993; young adults: mean = 18.67 (/33), SD = 4.22; older adults: mean = 25.45, SD = 3.75) as well as the denomination test from the Lexis (De Partz, Bilocq, De Wilde, Seron, & Pillon, 2001; young adults: mean = 55.5 (/64), SD = 2.55; older adults: mean = 58.27, SD = 3.88), with older adults systematically showing better semantic knowledge than younger ones (Mill-Hill: $t(44)$ = −5.75, $p < .001$; Lexis: $t(44)$ = −2.88, $p < .01$). All participants gave their informed consent before taking part in the study. The study was approved by the Ethics Committee of the Faculty of Psychology of the University of Liege. Two older participants were excluded from the analyses due to chance-level performance in the task.

Materials

Ninety-six pairs of semantically related object pictures were randomly selected from the materials used by Gronau and Shachar (2014) and Tibon et al. (2014) (see also Gronau, Neta, & Bar, 2008). These pairs were distributed across 14 categories (e.g., drinks, tools, housewares, kitchenware, animals, foods, and clothing). Unrelated pairs were formed by pairing stimuli from two related pairs (e.g., a knife and sunglasses; a hat and a baking dish), in such a way that those two stimuli together did not exhibit any semantic relationship. For each participant, object pairs were assigned to one of two conditions: 48 pairs were assigned to the related condition (e.g., tomatoes and a crate; pants and shoes) and additional 48 pairs were assigned to the unrelated condition. Importantly, presentation of each stimulus as a member of a related or unrelated pair was counter-balanced across participants. Sixty-four of these pairs were encoded, 32 related and 32 unrelated. Thirty-two additional pairs across the two relatedness conditions were not presented at encoding and were used as distractors in the retrieval phase. At retrieval, stimuli appeared in one of the six following conditions, each made up of 16 pairs: (1) intact–related; (2) intact–unrelated; (3) recombined–related (constructed using stimuli which were originally encoded in unrelated pairs, e.g., a hat and sunglasses); (4) recombined–unrelated (constructed using stimuli which were originally encoded in related pairs, e.g., tomatoes and shoes); (5) new–related; (6) new–unrelated. The assignment of stimuli to these conditions was fully counterbalanced across participants. As noted above, the "relatedness" assignment in the recombined condition represents the status of the pair at retrieval, as opposed to its status at encoding. The design of the task is illustrated in Figure 1.

During the experiment, the pictures were presented one above the other on a gray background. For related pictures, the two objects were presented in the typical spatial configuration in which they are encountered in everyday life (e.g., a lamp over a desk, a belt over a pair of pants). For unrelated pictures, the two objects were not usually associated with each other and their spatial configuration was uncommon. Objects' spatial locations were kept the same across related and the unrelated conditions. Picture size varied in order to account for scaling. Overall picture size was increased compared to the Tibon et al. (2014) study in order to be convenient for older adults as well. The object on-screen dimensions varied, with stimuli covering from 1.3° to 13° (height) and from 1.3° to 10.5° (width) of visual angle, with a distance between the stimuli comprising the pairs of 0.7°.

Procedure

Participants were tested individually at home in a quiet environment. After receiving all information concerning the experiment, they signed an informed consent form. They were then told that they were about to see pictures of pairs of objects and were asked to try to remember those pairs. Moreover, to guide their encoding, following Tibon et al. (2014), they were instructed to perform a comparison task which consisted of judging, for each pair, which one of the two objects was more expensive. They were instructed to press the "up arrow" on the keyboard if they thought that the upper object was more expensive, and the "down arrow" if they thought that the lower object was more expensive. The 64 pairs were presented one at a time for 3,500 ms each. The judgment about the most expensive object had to be given within this delay. This was followed by a 500-ms blank screen and a subsequent 500-ms fixation cross before the next pair appeared on the screen. Once the encoding phase was completed, participants were given a 5-min break filled with conversation before starting the retrieval phase. During the recognition memory test, pairs belonging to the six retrieval conditions described above were presented in random order. Participants were instructed to determine for each pair whether it was intact, recombined, or new, by pressing respectively the 1, 2, or 3 keys on the keyboard. The Remember/Know/Guess (RKG) responses were collected for "intact" responses only, in order to match old/new paradigms in which only "old" responses receive an RKG judgment. Following an "intact" response, a screen appeared prompting participants to specify whether they "remembered" (studied pair with retrieval of associated contextual details), "knew" (studied pair without retrieval of any contextual detail), or "guessed" that the pair was intact. Responses given during this retrieval phase were self-paced. Each response triggered a 500-ms blank screen and a subsequent 500-ms fixation cross, followed by the next trial.

Results

Accuracy

Means and standard deviations for accuracy scores in the two groups are shown in Table 1. Of note is the potential for ceiling effect in both age groups for intact related pairs. Mixed 2 (group: younger, older) $\times$ 2 (relatedness at retrieval: related, unrelated) $\times$ 3 (retrieval category: intact, recombined, new) ANOVAs with repeated measures on the second and third factors were conducted on the accuracy rates (as well as on the median reaction times, presented in Supplemental Materials). It evidenced a significant main effect of age, with poorer overall accuracy rates for older ($M = 75.99$) compared with younger adults ($M = 84.46$; $F(1,44) = 11.8$; $p < .01$, $\eta_p^2 = .21$), and a significant main effect of the retrieval category ($F(2,88) = 26.02$; $p < .001$, $\eta_p^2 = .37$), with better performance for new ($M = 89.88$) than for intact ($M = 79.72$) and recombined pairs ($M = 71.08$; planned comparisons, $p < .001$) and better performance for intact pairs than recombined ones ($p < .01$). There was no main effect of semantic relatedness on accuracy rates (related: $M = 80.16$, unrelated: $M = 80.29$; $F(1,44) = 0.01$; $p = .91$, $\eta_p^2 = .01$). Neither were there any significant group $\times$ retrieval category interaction (intact: young, $M = 82.03$, older, $M = 77.41$; recombined: young, $M = 78.39$, older, $M = 63.78$; new: young, $M = 92.97$, older, $M = 86.79$; $F(2,88) = 2.12$; $p = .13$,

$\eta_p^2 = .05$), nor group × relatedness interaction (young: related, $M = 84.29$, unrelated, $M = 84.64$; older: related, $M = 76.04$, unrelated, $M = 75.95$; F(1,44) = 0.04; $p = .84$; $\eta_p^2 = .01$), nor group × relatedness × retrieval category interaction (F(2,88) = 1.18; $p = .31$, $\eta_p^2 = .03$). In contrast, the retrieval category × relatedness interaction was significant (F(2,88) = 46.8; $p < .001$, $\eta_p^2 = .52$). Although semantic relatedness did not influence accuracy rates for new pairs (related: $M = 90.22$, unrelated: $M = 89.54$; planned comparison, $p = .68$), it significantly increased accuracy for intact related pairs compared with unrelated ones (related: $M = 88.28$, unrelated: $M = 71.16$; $p < .001$), and significantly decreased accuracy for recombined related pairs compared with recombined unrelated ones (related: $M = 61.99$, unrelated: $M = 80.17$; $p < .001$).

To compare recognition accuracy between relatedness conditions independently of response bias (e.g., a tendency to respond "intact" to related pairs due to their familiar configuration), d' indices were calculated for each participant using the distributions of the intact and the new condition as an index of item discrimination, and using the distributions of the intact and the recombined condition as an index of associative discrimination. Those were compared using planned comparisons in order to test our hypothesis of reduced differences in d' scores in young versus older adults for related pairs compared to the unrelated condition, that should express the age-related associative deficit with poorer d' in older than young adults. There was no difference in d' scores contrasting hits to intact pairs and false alarms to new pairs between young and older adults for related pairs ($p = .26$) nor for unrelated pairs ($p = .1$). The comparison between d' scores contrasting hits to intact pairs and false alarms to recombined pairs between young and older adults was significant for related pairs ($p < .01$) as well as for unrelated pairs ($p < .01$), younger adults displaying better performance in all cases.

Both d' scores are presented in Figure 2.

Our main prediction, expressed by the examination of the two d' distributions, was of greater advantage of semantically related over unrelated pairs for older than for young participants. This prediction was not confirmed by our ANOVAs. As with any form of classical null hypothesis testing however, absence of evidence is not evidence of absence. We therefore adopted recent proposals to use Bayesian factors, as implemented by JASP V0.8.0.1 (2016) (see Wagenmakers et al., 2016) to compare null and alternate hypotheses. We compared the null model with an alternative model that includes the interaction between semantic relatedness and age group. Main effects for the semantic relatedness and age group were apparent in all models (that is, assumed to be nonzero) and were therefore treated as nuisance factors. Analysis of d' scores contrasting hits to intact pairs and false alarms to new pairs using a JZS Bayes factor ANOVA with default prior scales revealed that the null model was preferred to the alternative model by a Bayes factor of 3.17. For d' scores contrasting hits to intact pairs and false alarms to recombined pairs, the null model was preferred to the alternative model by a Bayes factor of 2.64. The data thus provide evidence *against* the hypothesis that older participants' memory would benefit more than younger participants from semantic relatedness at encoding.

To sum up, accuracy analyses showed (1) better overall accuracy in young than older adults; (2) higher accuracy for new pairs than for recombined and intact ones, and better performance for intact pairs than for recombined ones; and (3) semantic relatedness improved performance for intact pairs, while it decreased performance for recombined pairs, and did not impact performance for new pairs. Given the switch between relatedness status at encoding and retrieval within the "recombined" condition, the effect of relatedness *at encoding* thus seems to consistently *improve* performance for both intact and recombined pairs (with the unrelated recombined pairs at retrieval, affected by the relatedness of the pairs at encoding, and vice-versa). Finally, global discrimination rates showed no effect of age on item discrimination (d' computed with the distribution of false alarms to new pairs), but a benefit of semantic relatedness across age groups. It also showed worse performance in older than in young adults for associative discrimination (d' computed with the distribution of false alarms to recombined pairs), which was not improved by semantic relatedness in either group.

Error analysis

As the three possible responses allowed for two types of errors, we also conducted error analyses. In order to limit the number of analyses, we focused on the error rates in the "recombined" retrieval category for which there were substantial responses of both "intact" (reflecting associative failure) and "new" (representing item memory failure) errors. We performed a 2 (group: younger, older) × 2 (relatedness: related, unrelated) × 2 (error type: intact vs. new) mixed ANOVA on the error rates (calculated by dividing the number of error of each kind by the total number of recombined pairs) with repeated measures on the second and third factors. This analysis revealed a significant main effect of group ($F(1,44) = 9.69$; $p < .01$; $\eta_p^2 = .18$) with more errors in older ($M = 18.11$) than in younger adults ($M = 10.81$), a significant main effect of relatedness ($F(1,44) = 40.06$; $p < .001$; $\eta_p^2 = .48$), showing more errors for related ($M = 19.00$) than unrelated ($M = 9.91$) recombined pairs, and a significant main effect of type of erroneous response, showing more erroneous "intact" ($M = 20.79$) than "new" ($M = 8.13$) responses ($F(1,44) = 26.11$; $p < .001$; $\eta_p^2 = .37$). The group × relatedness interaction was not significant (related: young, $M = 14.71$, older, $M = 23.29$; unrelated: young, $M = 6.9$, older, $M = 12.93$; $F(1,44) = 0.79$; $p = .38$; $\eta_p^2 = .02$), but the group × type of erroneous response interaction was significant ($F(1,44) = 4.24$; $p < .05$; $\eta_p^2 = .09$), with more erroneous "intact" than "new" responses given to recombined pairs both in young adults (erroneous "intact": $M = 14.58$, erroneous "new": $M = 7.03$; planned comparisons, $p < .05$) and, to a greater extent, in older adults (erroneous "intact": $M = 26.99$, erroneous "new": $M = 9.23$; $p < .001$). The relatedness × type of erroneous response interaction was also significant ($F(1,44) = 27.59$; $p < .001$; $\eta_p^2 = .39$), with more erroneous "intact" responses for related than unrelated pairs (related: $M = 29.65$, unrelated: $M = 11.92$; $p < .001$), but no effect of relatedness on erroneous "new" responses (related: $M = 8.36$, unrelated: $M = 7.91$; $p = .72$). The interaction between all three factors was not significant ($F(1,44) = 0.03$; $p = .85$; $\eta_p^2 = .01$).

To sum up, analyses of erroneous responses to recombined pairs showed globally more errors in older than in young adults, globally more errors regarding related recombined pairs (composed of stimuli that were unrelated at encoding) than unrelated ones (composed of stimuli that were related at encoding), suggesting that (1) relatedness at encoding induced fewer erroneous responses overall, and/or (2) relatedness at retrieval increased false associative recognition. Analyses also showed more erroneous "intact" responses than erroneous "new" responses, especially in older adults, probably due to item familiarity associated with a declining capacity for recollection-to-reject. This was also more often the case toward related than unrelated pairs.

Recollection and familiarity estimates

Analyses then focused on data of Remember/Know/Guess responses. First, we separately analyzed each of the three response categories (R, K, and G) for correct recognitions (i.e., hits to intact pairs) across relatedness conditions using 2 (group: younger, older) × 2 (relatedness: related, unrelated) mixed ANOVAs with repeated measures on the second factor; Remember and Know responses are presented in Figure 3. The analysis contrasting group and relatedness conditions for correct Remember responses showed that there was no main effect of group ($F(1,44) = 0.69$; $p = .41$; $\eta_p^2 = .02$), but a significant main effect of relatedness ($F(1,44) = 9.23$; $p < .01$; $\eta_p^2 = .17$), with more Remember responses for hits to related pairs compared with unrelated ones. There was no group × relatedness interaction ($F(1,44) = 2.10$; $p = .15$; $\eta_p^2 = .05$).

Analyses on familiarity estimates calculated using the Yonelinas and Jacoby (1995) IRK index (Independent Remember and Know: [Familiarity (IRK) = "Know"/(1 – R)], that take into account the fact that "know" responses are mathematically constrained by the proportion of "remember" responses) revealed a main effect of group ($F(1,44) = 12.64$; $p < .001$; $\eta_p^2 = .22$), with more familiarity responses in young than in older adults, a significant main effect of relatedness ($F(1,44) = 9.48$; $p < .01$; $\eta_p^2 = .18$), with more familiarity responses for hits to related pairs compared with unrelated ones. The group × relatedness interaction was also significant ($F(1,44) = 8.06$; $p < .01$; $\eta_p^2 = .15$), revealing that although young adults made greater use of familiarity when recognizing related than unrelated pairs (planned comparison, $p < .001$), there was no difference in the use of familiarity between related and unrelated pairs in older adults ($p = .87$). Analyses on correct Guess responses did not evidence any significant effect of group ($F(1,44) = 1.04$; $p = .31$; $\eta_p^2 = .02$) or of relatedness ($F(1,44) = 2.63$; $p = .11$; $\eta_p^2 = .06$) or any significant interaction ($F(1,44) = 2.63$; $p = .11$; $\eta_p^2 = .06$).

"Remember" judgments for false alarms in the "recombined" retrieval category were analyzed separately using a 2 (group: younger, older) × 2 (relatedness: related, unrelated) mixed ANOVA with repeated measures on the second factor. Erroneous "intact" response rates based on Know as well as Guess responses were not analyzed because of insufficient dispersion of the data. Data regarding Remember judgments accompanying erroneous

"intact" responses to recombined pairs should be viewed with caution, due to the low number of such responses to unrelated pairs' trials by young adults. Data are presented in Figure 4.

The analysis of Remember responses associated with false recognitions of recombined pairs showed a significant main effect of age group ($F(1,44) = 8.65$; $p < .01$; $\eta_p^2 = .16$), older adults making significantly more false recollections than young adults, and a significant main effect of relatedness ($F(1,44) = 25.58$; $p < .001$; $\eta_p^2 = .37$), related pairs leading to more erroneous "intact" responses on the basis of recollection than unrelated ones. The group × relatedness interaction was not significant ($F(1,44) = 1.55$; $p = .22$; $\eta_p^2 = .03$).

To sum up, semantic relatedness increased the use of recollection underlying both correct recognitions *and* false recognitions of recombined pairs across both age groups. Moreover, older adults were also more prone to false recollections than young adults, whatever the semantic relatedness condition. Semantic relatedness also increased the use of familiarity in correct recognition, particularly in young adults, who also globally used more familiarity than older adults, contrary to our original hypothesis.

Discussion

In this study, we tested whether bottom-up unitization induced by semantic relatedness between pairs of object pictures could alleviate older adults' associative deficit by allowing them to base their associative memory discrimination on familiarity (based on Tibon et al., 2014). We also considered the alternative possibility: that the semantic relatedness of memoranda would instead impair discrimination between intact and recombined pairs because of prior knowledge leading to a feeling of familiarity for distractors, which would prevent older adults from benefitting from unitization (Delhaye & Bastin, 2016; Gutchess & Park, 2009; Mohanty et al., 2016). We used a Remember/Know/Guess paradigm to characterize the processes underlying recognition decisions, predicting that recognition of related object pairs would be accompanied by an increase in the use of familiarity compared with unrelated pairs.

Regarding objective recognition accuracy, across age groups, we found evidence of the classic concordant effect, that is, an increase of both hit (to intact pairs) and false alarm rates (to recombined pairs) for semantically related compared with unrelated pairs, with no difference in global discrimination (d'). This finding generally reproduces Tibon et al.'s (2014) behavioral results using the same materials. The greater false alarm rate to recombined related pairs, which is generally attributed to processing fluency for related items leading to a false sense of familiarity, may here also reflect weaker encoding of pairs that were unrelated at encoding compared with those that were related and became unrelated in the recombination process. This concordant effect was previously reported in the literature studying the impact of preexisting knowledge on associative memory using different types of materials such as semantically related word pairs (categorical relationship; Greve et al., 2007) and compound words (Ahmad et al., 2015; Ahmad & Hockley, 2014). It is usually interpreted as indicating a greater contribution of familiarity to associative memory for

related compared with unrelated pairs. Importantly, this effect cannot only be attributed to a response bias toward related pairs, since the effect for intact pairs is much greater than the effect for new pairs.

Semantic relatedness and the age-related associative deficit

In regard to aging, the current results reproduce the standard finding of an age-related associative deficit. Moreover, the absence of an interaction between age group and semantic relatedness on global accuracy measures suggests that this deficit was not alleviated by semantic relatedness. This notion is also supported by the result of our Bayesian analysis, providing evidence in favor of the null hypothesis. Interestingly, the ability to recognize intact pairs was not affected by age, neither in global accuracy nor in error patterns. Rather, the older adults' associative deficit seems to stem from their difficulty in identifying recombined pairs as such, and a greater tendency to endorse them as intact than as new, irrespective of their semantic relatedness status, possibly due to confusion between episodic and semantic sources of fluency (a semantic link being present in all cases: related recombined pairs displayed a conceptually plausible spatial relationships at test, whereas unrelated recombined pairs contained items that were both studied in semantically related pairs). This result contrasts with previous findings that evidenced either a benefit of prior knowledge to older adults' associative memory performance (Badham et al., 2012; Badham & Maylor, 2015; Castel, 2005; Naveh-Benjamin et al., 2003; Patterson et al., 2009; see Umanath & Marsh, 2014 for a review), or an impairment in performance caused by semantic relatedness under certain boundary conditions (Badham et al., 2015; Delhaye & Bastin, 2016; Jäger et al., 2010; Mohanty et al., 2016), such as the presence of "shared relations" across the test list, providing ambiguous cues for memory discrimination, as it could have been the case here since several exemplars from a same thematic relationship were presented. However, here, surprisingly, semantic relatedness did not seem to impact older adults' performance, in contrast to the young adults, in which it did. This issue is further discussed in the next section.

Impact of semantic relatedness on familiarity and recollection estimates

The greater elicitation of familiarity by related pairs in young adults was highlighted using the Remember/Know/Guess paradigm. Relatedness indeed seems to have enhanced the reliance on associative familiarity for correct recognition in young adults, although it did not do so in older adults. In young adults, this effect is coherent with unitization theories that hold that unitization increases familiarity to intact pairs (Quamme et al., 2007; Yonelinas et al., 1999). Moreover, across age groups, recognition of related pairs was also accompanied by a greater contribution of recollection than recognition of unrelated pairs, which could seem surprising, as the recollection ERP correlate that was highlighted in the recognition of related pairs in Tibon et al.'s (2014) study was not greater than in the recognition of unrelated pairs. Here, the increase in reported recollection was observed both for hits and for false alarms. Again, this could be partly explained by a higher "intact" response rate in general for related than unrelated pairs. This finding of an increase in reported recollection for related pairs does not exclude the possibility that these related pairs were unitized in a bottom-up fashion at encoding, since recollection and familiarity processes operate independently and the occurrence of one does not exclude the occurrence of the other and

vice-versa (an unfortunate limitation of the Remember/Know/Guess paradigm being that it cannot capture this subtle phenomenon). Similar results of an increase in both familiarity *and* recollection contributions to recognition of unitized associations were also shown in an ERP study by Zheng, Li, Xiao, Broster, Jiang, & Xi (2015), as well as in Parks and Yonelinas (2015) behavioral study. Alternatively, this result could also be understood in the framework of Levels Of Processing theory (Craik & Lockhart, 1972), which states that manipulations of semantic memory influence subsequent episodic retrieval mostly by modulating recollection. That is, encoding stimuli in a deep—semantically meaningful— manner would improve their retrieval by increasing the strength of subsequent recollection, as opposed to shallow encoding, which is thought to engender recognition primarily on the basis of familiarity (Greve et al., 2007; Tibon et al., 2014; Yonelinas, 2002).

Another aspect of participants' response patterns is also likely to have induced this globally higher false alarm rate toward related recombined pairs. Stimuli comprising the related recombined pairs were all studied within unrelated pairs at encoding (a constraint dictated by the difficulty in recombining stimuli and preserving the same degree of relatedness as in the studied pairs). They may thereby have been less strongly remembered than stimuli that were in related pairs during encoding. This may have made the related recombined pairs more difficult to reject than unrelated recombined ones (in which the stimuli were studied in related pairs, possibly engendering deeper encoding of each stimulus). In other words, the experimental design in which the relatedness status of the recombined pairs was switched from encoding to retrieval may have facilitated correct rejections of unrelated recombined pairs as opposed to related recombined ones. Consistently with this possibility, Gutchess and Park (2009) showed that it was more difficult to reject recombined pairs when they are recombined within the same category than when their relatedness status changes from encoding to retrieval. More precisely, they suggested that on the one hand, relatedness facilitates encoding, but on the other hand, it can backfire at recognition by leading to more memory errors when a lure pair shares a naturally occurring relationship. Jones and Jacoby (2001) further suggested that meaning-based relationships at encoding improve the ability of individuals to use recollection-to-reject lure items in recognition tests (Cooper & Odegard, 2012; Odegard & Lampinen, 2005; Odegard, Lampinen, & Toglia, 2005). A similar suggestion was put forward by Dosher and Rosedale (1991), who stated that the use of recollection (and specifically, the use of a recall-to-reject strategy) to decide whether a pair is old or new was easier when this pair was pre-experimentally related than when a new connection had to be formed.

Finally, one limitation of the design of this study that could restrict our understanding of the implication of recollection and familiarity processes throughout the recognition task is the absence of RKG data for correctly identified recombined pairs, the condition that could have best captured actual associative memory. Such data could have allowed us to estimate the contribution of "recall-to-reject" processes to associative discrimination in this task. Moreover, the presence of RKG judgments for intact responses only could have given different weights to the different kinds of responses, although this is the classical way RKG is evaluated across the literature (cf. old/new paradigms).

Recollection and familiarity estimates in aging

Surprisingly, semantic relatedness did not enhance the use of familiarity in older adults' associative memory performance. Might it be that the putatively related pairs were not unitized at encoding, or even that their semantic relatedness was not perceived? This possibility seems unlikely given that (1) the semantic relationship was indeed perceived by young adults since it clearly impacted their performance, and (2) older adults showed higher semantic knowledge than younger ones on both semantic knowledge tests. Still, one possibility could be that the encoding instructions did not induce sufficient levels of unitization or did not encourage the processing of the relationship between the two items composing the pair. Instead, encoding instructions (to decide which one is the more expensive) emphasized processing of items individually rather than together. Older adults might have focused on that decision task and processed items individually, without any further time left within the allowed 3,500 ms to process further information due to decreased attentional resources (Craik, 1986) or to general slowing of processing speed (Salthouse, 2000). Such an interpretation could account for the absence of enhancement of familiarity for related pairs, as well as for the recollection results discussed below. This interpretation is supported by the observation of slower reaction times at encoding in older compared to young adults (see Supplemental Materials). Future studies should assess whether top-down unitization, with more contextualized encoding emphasizing the processing of semantic relatedness via the encoding instructions for instance, would alleviate the age-related associative deficit to a greater extent than did bottom-up unitization in the present procedure.

Moreover, older adults' associative performance was also characterized by a reduced ability to efficiently use recollection compared to young adults. This seems mainly due to enhanced false recollection rates (or more confident false recognition rates, in the framework of single-process models of recognition, e.g., Dunn, 2004; Wixted, 2009). Semantic relatedness did not seem to modify this profile. This also suggests that items composing the pairs might have been processed individually by older adults, irrespective of semantic relatedness. Alternatively, one could argue that some of the false recollection produced by older adults could actually reflect familiarity-based judgments (McCabe & Geraci, 2009). Altogether, this pattern of results gives some cues to understanding why older adults' associative performance was not improved by semantic relatedness.

The aging literature consistently provides evidence for an age-related increase in false recollection, especially in the context of semantically related materials (McCabe, Roediger, McDaniel, & Balota, 2009). For instance, in the Deese–Roediger–McDermott false memory paradigm (Roediger & McDermott, 1995), participants presented with a list of semantically related words systematically increase false alarm rates for lures semantically related to the target concept, along with higher levels of recollection than of familiarity (see Jou & Flores, 2013 for a review). Norman and Schacter (1997) showed that in this paradigm, older adults were more likely than young adults to make high-confidence errors and to report that they recollected specific details about the critical lures, as expressed in increased "remember" responses. Additionally, Henkel, Johnson, and De Leonardis (1998) showed older adults to be more likely to falsely recollect that they had seen an imagined item when it was either physically or conceptually close to those actually seen (see also Lyle, Bloise, & Johnson,

2006). In the current study, older adults falsely recollected related as much as unrelated recombined pairs. For both cases, our results could be understood in the framework of a "misrecollection account" of cognitive aging. The misrecollection account holds notably that, during encoding, older adults are more prone than younger ones to miscombine features from other studied events that occurred in close temporal proximity, in such a way that it produces a convincing and confidently held false recollection of those features (Dodson, Bawa, & Krueger, 2007). Such misrecollections in older adults could also occur when attempting to retrieve a particular target event, by activating and misremembering features from nontarget but similar events, i.e., semantically related ones. The critical point of this theory is that such misrecollections will be more often associated with high levels of confidence in responses of older adults compared with young adults. The authors attribute this phenomenon to disinhibited binding processes, in accordance with the ADH (e.g., Naveh-Benjamin, 2000). Seemingly, unitization should have ameliorated these age-related binding deficits, that was not the case in the current study. A limitation of this study is that it does not allow us to assess whether the deficits were not attenuated by unitization because of older adults' failure to unitize the pairs in memory during encoding (cf. strategy utilization deficit, Dunlosky & Hertzog, 1998; Naveh-Benjamin et al., 2007), or whether they indeed encoded the pairs in a unitized fashion and the deficits are due to a retrieval failure triggered by an activation of semantically related features of lures. Comparison of our results with results from top-down unitization might further elucidate this remaining question.

Conclusion

In this study, although semantic unitizability of the memoranda increased the contribution of both familiarity and recollection processes in young adults, it did not improve older adults' performance. Rather, older adults showed an equivalent associative memory decline, characterized by no increase in the use of familiarity for correct recognition, but increased correct *and* false recollection rates. This might be due to some boundary conditions in the instructions during encoding. These findings might further be interpreted in terms of a "misrecollection account" according to which older adults would tend to produce more false alarms to recombined pairs, with particularly high confidence, due to disinhibited binding processes.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

Acknowledgments

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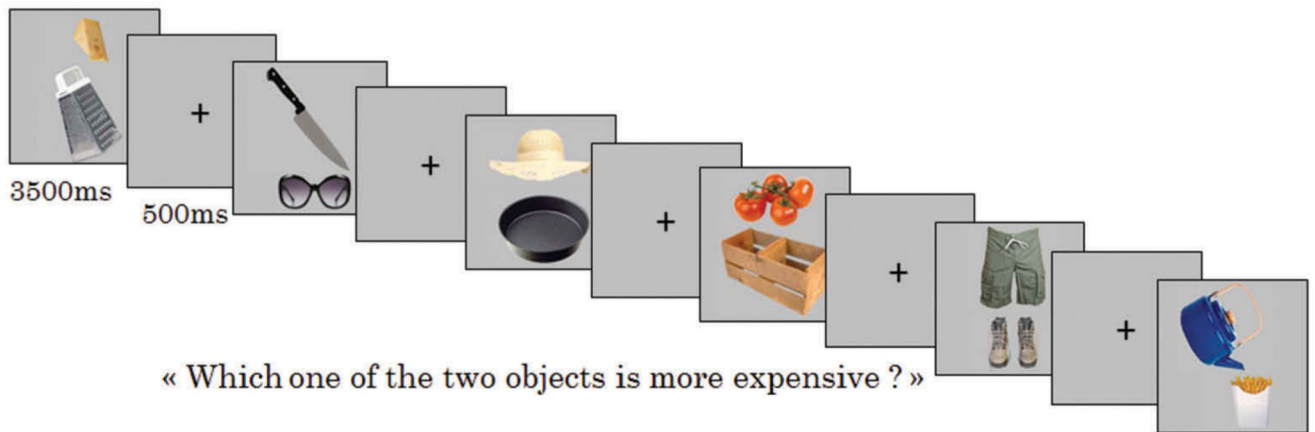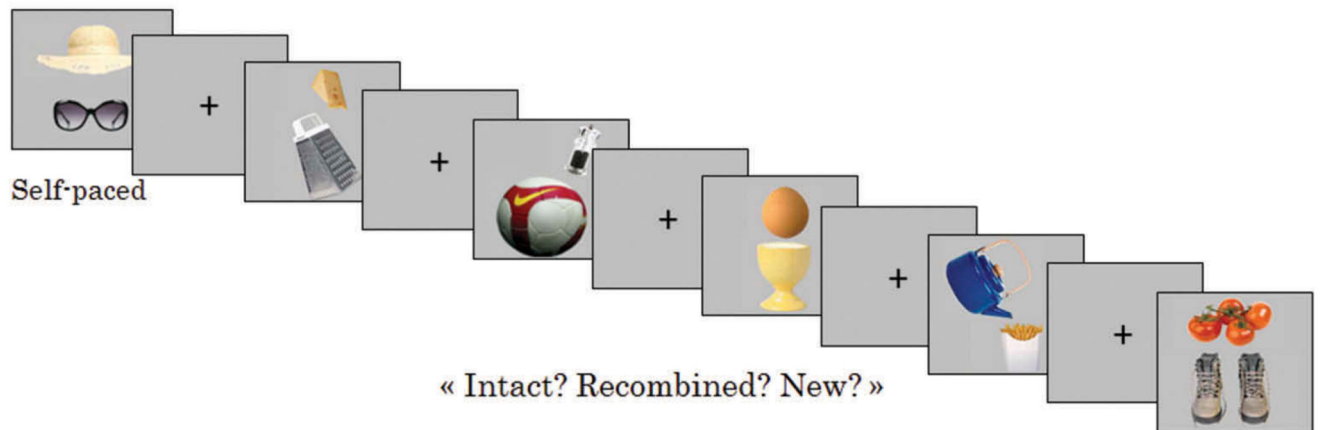
Encoding phase:

3500ms   500ms

« Which one of the two objects is more expensive ? »

Recognition phase:

Self-paced

« Intact? Recombined? New? »

Figure 1.
Illustration of the design with instances of related and unrelated pairs at encoding (top), and intact–related; intact–unrelated; recombined–related; recombined–unrelated; new–related; new–unrelated pairs at recognition (bottom).
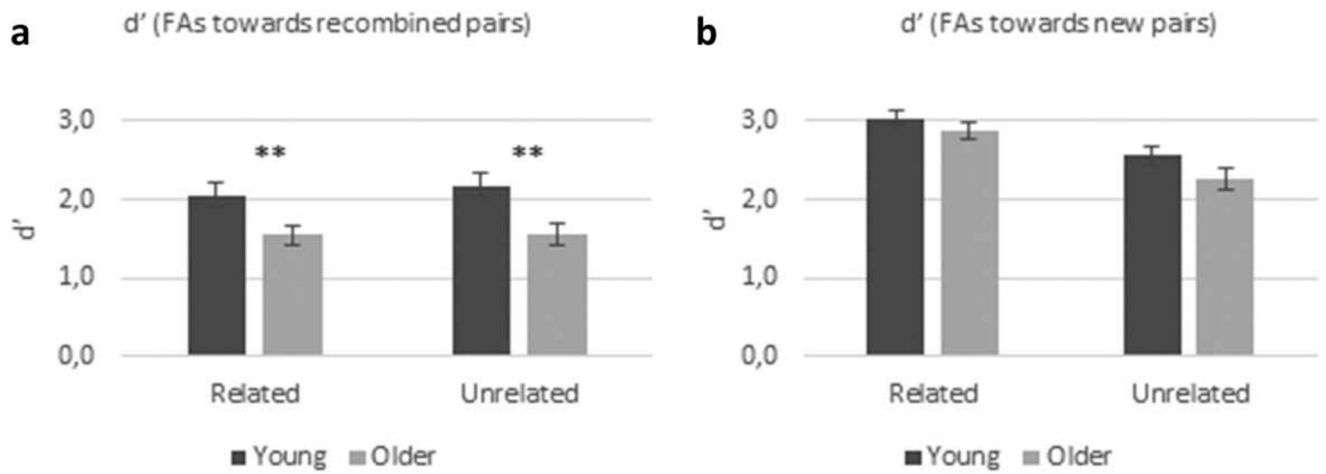
Figure 2.
d' Scores contrasting hits to intact pairs and (a) false alarms to recombined pairs and (b) false alarms to new pairs across groups and relatedness conditions.
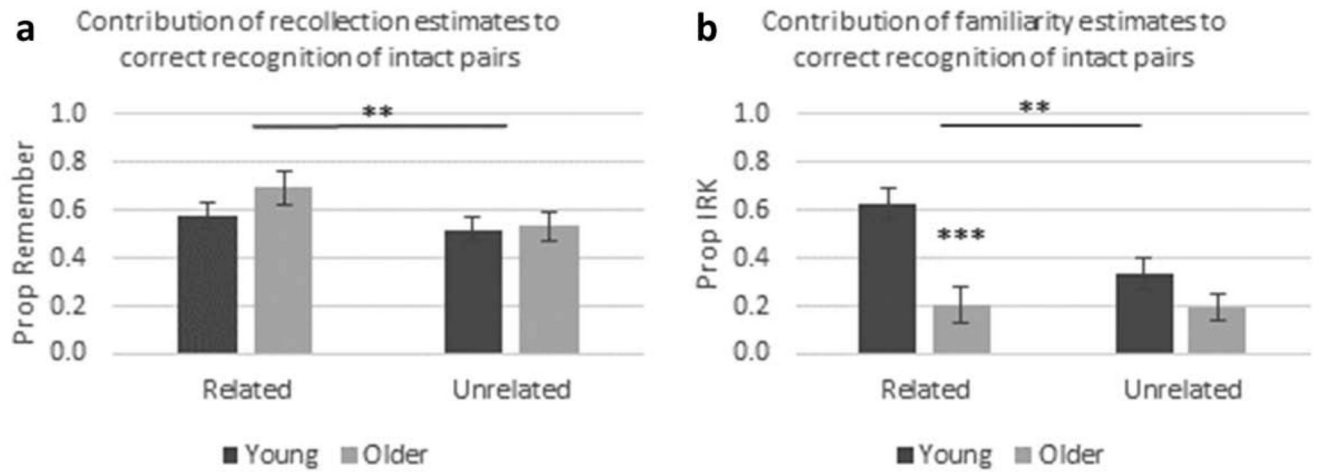
Figure 3.
Contribution of recollection (a) and familiarity (b) estimates to correct recognitions across groups and relatedness conditions.
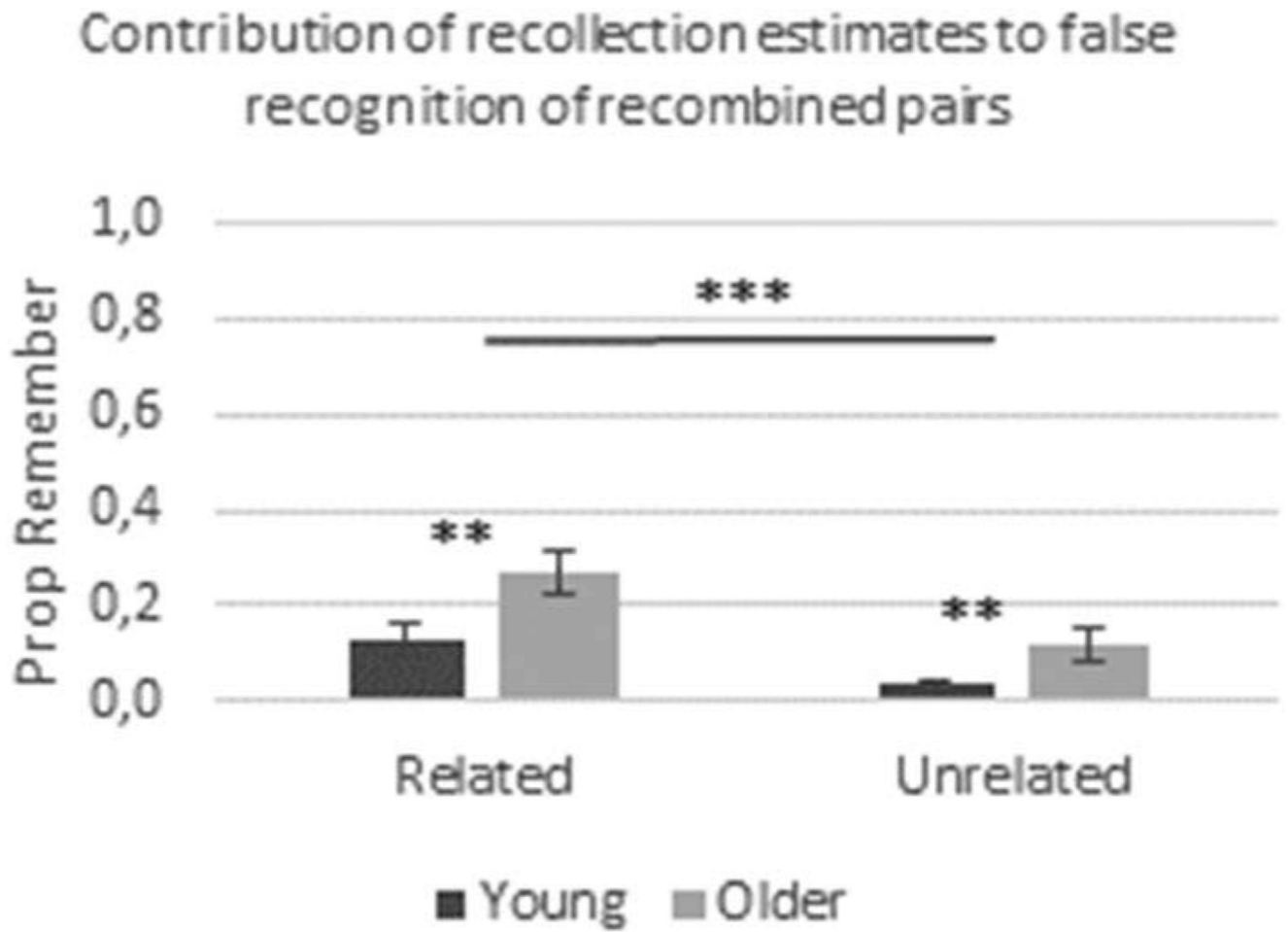
Figure 4.
Contribution of recollection estimates to false recognitions of recombined pairs across groups and relatedness conditions.

Table 1

Response rates across groups, retrieval categories, and relatedness conditions.

	Retrieval category and relatedness at retrieval											
	Intact				Recombined				New			
	Related		Unrelated		Related		Unrelated		Related		Unrelated	
% Response	Young	Older	Young	Older	Young	Older	Young	Older	Young	Older	Young	Older
Intact	89.06 (10.47)	87.5 (12.5)	75 (17.68)	67.33 (19.38)	22.66 (22.1)	36.65 (19.22)	6.51 (8.34)	17.33 (17.98)	0.78 (2.8)	3.12 (6.61)	0.52 (1.76)	1.42 (3.3)
Recombined	8.59 (8.2)	9.37 (9.6)	22.4 (16.78)	25 (15.31)	70.57 (21.61)	53.41 (20.02)	86.2 (11.05)	74.15 (20.26)	5.99 (7.92)	9.66 (10.86)	6.77 (7.8)	12.22 (11.49)
New	2.6 (4.09)	3.12 (5.37)	2.34 (4.44)	7.67 (7.45)	6.77 (7.35)	9.94 (9.18)	7.29 (7.96)	8.52 (7.85)	93.23 (8.63)	87.22 (15.37)	92.71 (8.38)	86.36 (12.45)