# How to Induce an Age-Related Benefit of Semantic Relatedness in Associative Memory: It's All in the Design

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Abstract

The age-related associative memory deficit can be alleviated, under some conditions, when to-be-remembered associations are semantically related. In this study, we explored the experimental conditions in which older adults benefited from semantic relatedness and those that hindered any associative memory improvement. We did so by manipulating the level of semantic support within the associations presented at encoding and within the recombined pairs (i.e., the lures) at retrieval, such that pairs with high semantic support at encoding were recombined into pairs with equally high or with lower level of semantic support, and vice versa. We predicted that semantic relatedness would benefit older adults' associative memory when there was a decrease in semantic support from encoding to retrieval. Conversely, older adults' associative memory would be hindered when a recombination was equally or more familiar than the studied association. In Experiment 1, we manipulated the presence versus absence of semantic relatedness within associations both at encoding and at retrieval. In Experiment 2, we manipulated the frequency of related associations at encoding and at retrieval. Taken together, the results showed that older adults' associative memory was better in conditions in which associations closely matched semantic knowledge at encoding and were recombined into associations with no or less semantic support at retrieval. In contrast, older adults' performance was worse for semantically poorer associations at encoding, that were recombined into associations with greater semantic support at retrieval. This suggests that older adults' associative memory can be improved by semantic support under specific experimental conditions only.

*Keywords*: episodic memory; associative memory; aging; prior knowledge

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Aging is accompanied by a decline in episodic memory, which is thought to be partly due to an associative memory deficit (Naveh-Benjamin, 2000) by which older adults encounter difficulties in encoding and retrieving associations between pieces of information while their memory for single items is relatively better preserved. Relatedly, older adults display deficits in recollection, that is, the controlled retrieval of information within its encoding context, thus thought to be necessary in associative memory tasks, but preserved familiarity, that is, the feeling of having seen an item before without recall of its encoding context (Koen & Yonelinas, 2014; Yonelinas, 2002; Yonelinas, Aly, Wang, & Koen, 2010). The age-related associative deficit is characterized in particular by an increase in false associative recognitions (Kilb & Naveh-Benjamin, 2011), including conjunction errors (when a lure composed of features from studied stimuli is falsely recognized as being previously encountered) and gist-based errors (based on overall perceptual and conceptual similarity, thought to rely on familiarity, rather than based on item-specific information which is thought to rely on recollection, Brainerd & Reyna, 2002).

Mechanisms accounting for such greater susceptibility to false recognition in older adults are multiple, intertwined and thus not exclusive (see Devitt & Schacter, 2016, for a review): (1) impaired recollection processes as well as impaired retrieval strategies (Cohn, Emrich, & Moscovitch, 2008) such as associative identification (i.e., instantiation of a recall-like process at retrieval to overcome the familiarity associated with studied items that are recombined in a novel way and to reject them in favor of intact items) and recall-to-reject (i.e., correct rejection of a lure despite its high familiarity based on the recall of logically inconsistent information); (2) overreliance on familiarity; and (3) decline in memory monitoring processes thought to help withstanding interference from familiar information during associative recognition (Fandakova, Shing, and Lindenberger, 2013).

Recent research has explored strategies to improve older adults' associative memory. One of these strategies is unitization, that is, the encoding of an association as an integrated whole (Graf & Schacter, 1989). This strategy would allow older adults to recognize unitized associations using their preserved familiarity, rather than recollection (Yonelinas, 2002; Yonelinas et al., 2010). Two kinds of experimental strategies have been employed to induce unitization. One way relies on an "active strategy" (Ahmad, Fernandes, & Hockley, 2015) and occurs following explicit encoding instructions. Such unitization instructions induce the processing of the association in a unitized fashion, as opposed to processing a pair of stimuli as two separate, although associated, items. Another way to experimentally achieve unitization is thought to stem from a "passive strategy" that is implemented by the subject in the presence of the experimental materials without the need for explicit unitization instructions. In this case, unitization is induced and fostered by optimizing the existing features of the materials, such as perceptual features or the presence of a semantic relationship between the to-be-remembered items (Ahmad et al., 2015; Tibon, Gronau, Scheuplein, Mecklinger, & Levy, 2014).

The interest of studying a passive strategy to induce unitization in aging through the presence of a semantic relationship comes from the idea that semantic memory – the memory for general knowledge and facts about the world – remains well preserved in aging and could thereby support the declining episodic memory (Umanath & Marsh, 2014). Semantic relatedness could for instance help older adults to implement encoding and retrieval strategies, which they are otherwise less likely to put in place (Naveh-Benjamin, Brav, & Levy, 2007). Additionally Ofen and Shing's (2013) model of differential aging across memory systems posits that memory during aging is less capable of representing unique perceptual and episodic details and becomes increasingly anchored and reliant on prior knowledge which is still available during aging. Semantic relations could moreover allow older adults to capitalize on overlapping neural representations, and the co-activation of features shared by semantically related items may strengthen the associative memory representation that links them. This idea is operationalized in models of the cognitive architecture such as the Node Structure Theory (NST, Mackay, 1987) or the Source of Activation Confusion model (SAC, Reder, Paynter, Diana, Ngiam, & Dickison, 2007), that hold that information is represented as a set of interconnected concepts, which they refer to as “nodes”. Concept nodes are linked to semantically related nodes as well as to nodes representing their constituent features and to episode nodes that provide information about having encountered the concept in a given context. When nodes are activated, they prime all the nodes they are connected to, which in turn prime the other nodes they are connected to. Thus, any piece of information from conscious experience is linked not only to the episode node but also to perceptual and conceptual nodes. Adequate transmission of this priming is critical to learning and memory. According to the transmission deficit hypothesis of NST (MacKay & Burke, 1990), the transmission of priming between all nodes in the network weakens with aging, leading to difficulties in learning and remembering new information in older adults. This effect of age may however be variable depending on the number of connections of a concept in the network as well as the number of previous activations of this concept. Indeed, although the strength of connections between nodes decreases with aging, the number of connections between concepts increases because of greater lifelong experience with concepts, such that, when task demands rely on pre-existing connections, older adults’ binding difficulties might be reduced. However, when concepts only have single connections, then the effect of age is thought to be disproportionately detrimental in associative memory (James, Fogler, & Tauber, 2008).

Thus, several studies have assessed the impact of a passive strategy of unitization, mainly by manipulating semantic congruency or relatedness between to-be-remembered associations, on the associative memory deficit with age (see Table 1). Some observed a reduction of the age-related associative deficit (Ahmad et al., 2015; Badham, Estes, & Maylor, 2012; Badham et al., 2012; Badham & Maylor, 2015; Bastin et al., 2013; Castel, 2005; Castel, McGillivray, & Worden, 2013; D'Angelo, Noly-Gandon, Kacollja, Barense, & Ryan, 2017; D'Angelo et al., 2016; McGillivray & Castel, 2010; Naveh-Benjamin, Hussain, Guez, & Bar-On, 2003; Ostreicher, Moses, Rosenbaum, & Ryan, 2010; Patterson, Light, Van Ocker, & Olfman, 2009; Ryan et al., 2016; Smyth & Naveh-Benjamin, 2018; Zheng, Li, Xiao, Broster, & Jiang, 2015). However, others failed to show any age-related benefit of unitization for associative memory (Badham & Maylor, 2016; Bridger et al., 2017; Cooper & Odegard, 2012; Delhaye & Bastin, 2018; Delhaye, Tibon, Gronau, Levy, & Bastin, 2017; Gutchess & Park, 2009; Jäger, Mecklinger, & Kliegel, 2010; Memel & Ryan, 2017).

Some of these inconsistencies in the literature can be reconciled if one considers some boundary conditions. This has been conceptualized within the SAC framework (Reder et al. 2007). This model indeed considers that different nodes can have different base level of activation depending on how often a concept node has been encountered previously. The base-level of activation of a node, as well as the information about whether the node has recently been encountered, can affect the familiarity of a given concept. Thus, according to this model, because familiarity can arise from multiple causes (base-level activation versus recent exposure), responses in a recognition task based on the concept node alone (i.e., familiarity-based responses), without retrieval of the episode node, are error prone. Thus, based on the idea that different sources might contribute to familiarity (Coane, Balota, Dolan, & Jacoby, 2011; Reder et al., 2007), some authors propose that accurately rejecting lures that are recombinations of studied items *within* instead of *across* semantic categories increases the difficulty of associative memory discrimination because of the possible confusion between pre-experimental (i.e., absolute or baseline familiarity signal) and experimental familiarity (i.e., relative increase in baseline familiarity as a result of a study event) of semantic associations (Zacks, Hasher, & Li, 2000). Regarding the literature on normal aging, the SAC framework argues that concepts' base-level activation as well as their number of connections (their fan) increase with age, so that there would be an increased tendency to false alarm to items on the basis of familiarity judgments (Buchler & Reder, 2007).

Experimental evidence supporting these assumptions was put forward by associative memory studies of Badham, Hay, Foxon, Kaur, and Maylor (2015), of Mohanty, Naveh-Benjamin, and Ratneshwar (2016), and of Peterson, Schmidt and Naveh-Benjamin (2017), which all focused on semantic relatedness between the items to be remembered. In Badham et al.'s (2015) study, where associative memory was assessed using cued recall, the age-related associative deficit was attenuated for a "unique relation" condition, in which each association on the study list exhibited a specific relatedness relationship, but not for a "shared relations" condition, in which multiple associations on the list belonged to the same semantic category. The authors suggested that prior knowledge could be useful to older adults' associative memory only when it provides an extra strategy or extra cues to guide retrieval, which operate in addition and are complementary to the episodic memory trace itself (e.g., using the concept "the target was related to the cue"). In a similar vein, testing associative recognition memory using recombinations of related pairs *within* semantic categories such that the foils were related to the study pairs, Mohanty et al. (2016) emphasized a boundary condition whereby semantic relatedness hindered older adults' associative memory performance when the relatedness cue was equivocal for recognition (i.e., when only using the relatedness cue is not sufficient nor reliable for accurate discrimination and can be misleading). Patterson et al. (2009) further showed that, during associative recognition, older adults were more likely to endorse new related than new unrelated word pairs, while there was no such difference in young adults. Similarly, Delhaye and Bastin (2018) reported an increase in age-related false recognition of recombined compound words suggesting that older adults could find it difficult to differentiate between the experimental familiarity of the studied associations and the pre-experimental familiarity of lures sharing similar semantic relationships.

In contrast, there is evidence that recombining associations *across* categories can provide efficient strategic cues that enable older adults to benefit from prior knowledge. For instance, Peterson et al. (2017) showed that a change in the level of prior knowledge support between encoding and recognition (congruent face-name pairs recombined into incongruent ones) reduced older adults' associative deficit (for similar findings, see Fine, Shing, & Naveh-Benjamin, 2018). In this context, recombined incongruent pairs can be identified as such, and familiarity-based false recognitions can be overridden using strategic retrieval processes (e.g., recall-to-reject). Indeed, when one is aware that congruency changed between encoding and retrieval, one can use this change as a distinctive cue to discriminate between intact and recombined pairs (Fine et al., 2018; Peterson et al. 2017). However, the benefit of a change in the level of prior knowledge support between encoding and retrieval might work only unilaterally. That is, recombining unrelated word pairs at encoding into related word pairs at recognition should not alleviate older adults' associative deficit (Patterson et al., 2009). This condition requires both the encoding of arbitrary unrelated associations and the rejection of pre-experimentally very familiar recombinations at retrieval, two cognitive processes that decline in normal aging.

<Insert Table 1 about here>

Taken together, these findings emphasize that whether to-be-remembered associations are congruent with prior knowledge and, more importantly, how these associations are recombined between encoding and retrieval, are factors – boundary conditions – that influence age-related associative memory differences. Still, to the best of our knowledge, although many studies have investigated the age-related benefit of prior semantic knowledge for associative recognition and its boundary conditions, no study has directly compared the various boundary conditions within the same verbal associative memory task, and thus direct evidence to reconcile the divergent findings of previous studies is sparse.

In this study, we intended to extend the results of prior similar studies (Badham et al., 2015; Fine et al., 2018; Gutchess & Park, 2009; Mohanty et al., 2016; Patterson et al., 2009; Peterson et al., 2017) and more systematically investigate the conditions in which older adults benefit from semantic relatedness in associative memory, and those that counteract any age-related benefit from semantic relatedness, possibly due to increased reliance on familiarity, together with impaired recollection and strategic retrieval processes. To do so, in Experiment 1, we systematically manipulated the relatedness of the associations, both at encoding and when recombined, in such a way that we could explore all potential scenarios. Relatedness was manipulated by comparing pairs of items belonging to a given category, so sharing a lot of concept nodes (MacKay, 1987), with pairs of unrelated items. In Experiment 2, in order to further explore the influence of the absolute familiarity of associations, we systematically manipulated the frequency of categorically-related associations, both at encoding and when recombined. Here, the distinction was made, within pairs of items with many connected nodes (MacKay, 1987), in terms of the strength and fan of the connections, with pairs having higher versus lower baseline level of activation (Reder et al., 2007).

We hypothesized that older adults would display an associative memory deficit instead of a benefit from unitization when a recombination was as familiar as or more familiar (because of its absolute familiarity) than the studied association. The effect of the absolute familiarity of lures on older adults' performance should be characterized by increased false alarm rates in response to highly familiar recombinations, possibly reflecting a failure to implement efficient retrieval strategies to counteract the familiarity of the lures. We expected this to happen, in Experiment 1, when the recombinations were related (i.e., when the pairs are recombined *within* a category), and in Experiment 2, when the recombinations had high associative frequency. Moreover, the effect should be enhanced when the encoding conditions did not allow for much support from prior semantic knowledge, such as when pairs at encoding were unrelated (Experiment 1) or had low associative frequency (Experiment 2).

## Experiment 1

### Methods

**Participants.** Number of participants recruited in each group was determined by power analyses using G*Power software v3 (Faul, Erdfelder, Lang, & Buchner, 2007) for a 0.95 power, based on previous studies' effect sizes with similar design (Naveh-Benjamin et al., 2003, effect size $d = 0.86$). Thirty-four young adults and 34 healthy older adults took part in the study. Demographic information are presented in Table 2. All participants were recruited from the local community, were fluent French speakers, had normal or corrected-to-normal vision and hearing, and reported no history of neurological or psychiatric disorders. None of the older adults displayed any sign of cognitive impairment according to the Mattis Dementia Rating Scale (all within norms as determined by each subject's age; Pedraza et al., 2010). Young and older participants were matched for years of education as demonstrated by a non-parametric Mann-Whitney U-test used due to a violation of the equal variance assumption (U = 506, $p = .38$). The older adults displayed better vocabulary abilities than the young adults ($t(66) = 2.72$; $p < .01$) on the Mill Hill Vocabulary test (/33; Part B; Deltour, 1993). The study was approved by the Ethics Committee of the Faculty of Psychology of the University of Liège.

<Insert Table 2 about here>

**Materials.** One hundred sixty-four concrete words from 20 categories were selected from the Dubois and Poitou (2002) and Bueno and Magherbi (2009) databases (from 5 to 10 words/category depending on the category). These categorization norms were elaborated using the responses of a student population. Of these words, 144 were organized in semantically related pairs (two words belonging to the same category) and unrelated pairs (two words belonging to different categories). The 20 remaining words were used as distractors in the item test described below. Related pairs were strictly restricted to categorical relationships (e.g., *lion – tiger*). Related and unrelated pairs were formed using the same materials, such that each word belonged to two related pairs and two unrelated pairs (see Table 3 for an example). Each word pair was displayed in only one of these configurations at encoding, and in only one (the same or a recombined configuration) at retrieval. This allowed us to build six versions of the task in order to fully counterbalance the materials across conditions and participants.

<Insert Table 3 about here>

**Procedure.** Participants completed the task individually on a laptop computer using E-Prime 2.0 software (Psychology Software Tools, Pittsburgh, PA). After receiving all the information concerning the experiment, all participants signed an informed consent form. Two study-test cycles were completed with a short break (2 minutes) in between. This was done to avoid fatigue effects due to the length of the list. At the beginning of the study phase, participants were instructed to study the associations between the words. For each cycle, thirty-six pairs were encoded at a rate of 6 seconds each, with a 500-ms blank screen and a 500-ms fixation cross between trials. Eighteen pairs were presented in their semantically related configuration and 18 pairs were presented in their unrelated configuration. The order of presentation of the study pairs was randomized. After a 5-minute distracting phase filled with mental calculations, participants took part in an associative recognition test, in which 30 pairs were presented: 5 of the pairs that were related at encoding were presented in the same configuration as during encoding (related-intact); 5 of the pairs that were unrelated at encoding were presented in the same configuration as during encoding (unrelated-intact); 5 of the pairs that were related at encoding were recombined with other words from the same category (related-recombined related; RR); 5 of the pairs that were related at encoding were recombined with words from a different category (related-recombined unrelated; RU); 5 of the pairs that were unrelated at encoding were recombined with words from their own category (unrelated-recombined related; UR); and finally, 5 of the pairs that were unrelated at encoding were recombined with other words from a different category (unrelated-recombined unrelated; UU). For each pair presented, participants had to decide whether it was intact or recombined.

We also included an item recognition test in which participants' memory for single items was tested. For each cycle, in the item test, 20 single words were presented: 10 old words that had been studied during encoding and 10 new words that had never been seen previously. Among the old items, 5 words belonged to related pairs at encoding and 5 belonged to unrelated pairs at encoding. Among the new items, 5 words belonged to the same category as word pairs that were presented at encoding and 5 belonged to a category that had not been presented at encoding. In this item test, participants were instructed to decide whether the words were old or new.

Both recognition tests were self-paced. The order of presentation of the two study-test cycle, as well as, within each cycle, the order of presentation of the item and associative tests, were counterbalanced across participants.

**Data analyses.** Results from the two study-tests cycles were merged for the analyses. Analyses were conducted using mixed ANOVAs and follow-up tests were run using Bonferroni post hoc tests in Statistica. Partial eta square effect sizes were reported for ANOVAs, and Cohen's d effect sizes were reported following Bonferroni comparisons. The alpha level was set at .05.

**Results**

The hit and false alarm (FA) rates and *d'* measures across groups and conditions are reported in Table 4. We conducted a mixed ANOVA on the hit rates separately for each test type (item, associative), with relatedness at encoding (2: related, unrelated) as within-subject factors and group (2: young, older) as between-subject factor. In the item test, it revealed a main effect of relatedness ($F(1,66) = 37.61$; $p < .001$; $\eta^2_p = .36$), with higher hit rates for words that were related at encoding compared with the unrelated; a main effect of group ($F(1,66) = 17.25$; $p < .001$; $\eta^2_p = .21$), with higher hit rates for young than older adults, and there was a significant interaction between relatedness and group ($F(1,66) = 4.18$; $p < .05$; $\eta^2_p = .06$), characterized by a greater group difference for unrelated ($mean_{young} = .76$, SD= 0.16; $mean_{older} = .57$, SD = 0.2; Bonferroni, $p < .001$) than related words ($mean_{young} = .84$, SD= 0.13; $mean_{older} = .74$, SD = 0.16; Bonferroni, $p = .09$). For the associative test, there was a significant main effect of relatedness ($F(1,66) = 31.28$; $p < .001$; $\eta^2_p = .32$), with higher hit rates for related than unrelated pairs at encoding and a significant main effect of group ($F(1,66) = 8.41$; $p < .01$; $\eta^2_p = .11$), with higher hit rates for young than older adults, but the relatedness x group interaction was not significant ($F(1,66) = 3.03$; $p = .09$; $\eta^2_p = .04$).

We then computed mixed ANOVAs on the FA rates separately for each type of test. For the item test, an ANOVA with relatedness of lures (2: related, unrelated) as within-subject factor and group (2: young, older) as between-subject factor showed no main effect ( relatedness of lures: $F(1,66) = 1.18$; $p = .28$; $\eta^2_p = .02$; group: $F(1,66) = 0.09$; $p = .76$; $\eta^2_p = .01$), and no interaction ($F(1,66) = 3.29$; $p = .07$; $\eta^2_p = .05$). Regarding the associative test, we conducted a mixed ANOVA on the FA rates for recombined pairs with relatedness at encoding (2: related, unrelated) and relatedness at retrieval (2: related, unrelated) as within-subject factors, and group (2: young, older) as between-subject factor. It revealed a significant main effect of relatedness at encoding ($F(1,66) = 19.25$; $p < .001$; $\eta^2_p = .23$), with higher FA rates for pairs that were originally unrelated at encoding; a main effect of relatedness of the recombination ($F(1,66) = 29.24$; $p < .001$; $\eta^2_p = .31$), with higher FA rates for pairs that were recombined as related at retrieval; and a main effect of group ($F(1,66) = 15.95$; $p < .001$; $\eta^2_p = .19$), with higher FA rates in older than in young participants. There was a significant double interaction between relatedness at encoding and relatedness at retrieval ($F(1,66) = 7.51$; $p < .01$; $\eta^2_p = .1$): when the pairs were recombined as related at retrieval, there were as many FAs for related as for unrelated pairs at encoding ($mean_{RR} = .26$, SD = 0.2; $mean_{UR} = .28$, SD = 0.23; Bonferroni, $p = 1.00$), while when the pairs were recombined as unrelated at retrieval, there were fewer FAs for those that were related at encoding compared with those that were unrelated at encoding ($mean_{RU} = .11$, SD = 0.15; $mean_{UU} = .22$, SD = 0.21; Bonferroni, $p < .001$). There was no relatedness at encoding x group interaction ($F(1,66) = 0.27$; $p = .61$; $\eta^2_p = .01$). Critically, there was a significant double interaction between relatedness of the recombination and group ($F(1,66) = 13.27$; $p < .001$; $\eta^2_p = .17$), showing that there was no group difference in FA rates when the pairs were recombined as unrelated at retrieval ($mean_{young} = .13$, SD= 0.17; $mean_{older} = .2$, SD = 0.19; Bonferroni, $p = .53$), but that older adults had an increased

FA rate when the pairs were recombined as related at retrieval, both compared with young adults ($mean_{young}$ = .17, SD= 0.17; $mean_{older}$ = .37, SD = 0.21; Bonferroni, $p < .001$) and compared with their FA rate when the pairs were recombined as unrelated (Bonferroni, $p < .001$). There was no interaction between relatedness at encoding, relatedness at retrieval and group ($F(1,66) = 0.02$; $p = .89$; $\eta^2_p = .01$).

<Insert Table 4 about here>

We also calculated discrimination performance indices (*d′*) (Macmillan & Creelman, 2005), which we compared separately for each type of test. In the item test, this was done using the distribution of hit rates for old items and the distribution of FA rates for lures. A mixed ANOVA on relatedness (2: related, unrelated) and group (2: young, older) showed a significant main effect of relatedness ($F(1,66) = 9.65$; $p < .01$; $\eta^2_p = .13$), with a better discrimination performance for related than unrelated items; and a main effect of group ($F(1,66) = 7.35$; $p < .01$; $\eta^2_p = .1$), with better performance by young than older adults. There was no interaction between relatedness and group ($F(1,66) = 0.08$; $p = .78$; $\eta^2_p = .01$).

In the associative test, we calculated *d′* using the distributions of hit rates for intact pairs and of the FA rates to recombined pairs. We thereby obtained 4 *d′* scores: (a) distribution of hit rates for intact related pairs – distribution of FA rates for RR recombined pairs (i.e., related pairs at encoding that were recombined as other related pairs at retrieval; *d′* RR); (b) distribution of hit rates for intact related pairs – distribution of FA rates for RU recombined pairs (*d′* RU); (c) distribution of hit rates for intact unrelated pairs – distribution of FA rates for UR recombined pairs (*d′* UR); and (d) distribution of hit rates for intact unrelated pairs – distribution of FA rates for UU recombined pairs (*d′* UU). *d′* discrimination performance indices for the associative test in each group and condition are represented in Figure 1. A mixed ANOVA with relatedness at encoding

(2: related, unrelated) and relatedness at retrieval (2: related, unrelated) as within-subject factors, and group (2: young, older) as between-subject factor revealed a main effect of relatedness at encoding ($F(1,66) = 45.83$; $p < .001$; $\eta^2_p = .41$), with better *d'* for pairs that were related at encoding; a main effect of relatedness at retrieval ($F(1,66) = 33.1$; $p < .001$; $\eta^2_p = .33$), with better *d'* for pairs that were unrelated at retrieval; and a main effect of group ($F(1,66) = 20.95$; $p < .001$; $\eta^2_p = .24$)[i], with better performance in young than in older participants. There was also a significant double interaction between relatedness at encoding and at retrieval ($F(1,66) = 9.35$; $p < .01$; $\eta^2_p = .12$): for pairs that were related at encoding, there was better performance when they were recombined as unrelated (RU) than as related (RR) ($mean_{RR} = 1.7$, SD = 0.87; $mean_{RU} = 2.21$, SD = 0.77; Bonferroni, $p < .001$; Cohen's d = 0.70), while for pairs that were unrelated at encoding, performance also tended to be greater when they were recombined as unrelated (UU) than as related (UR), but the effect was smaller ($mean_{UR} = 1.22$, SD = 1.07; $mean_{UU} = 1.42$, SD = 1.04; Bonferroni, $p = .06$; Cohen's d = 0.21). In both cases of related recombinations, pairs that were related at encoding were better recognized than those that were unrelated at encoding (Bonferroni, $p < .001$). There was no encoding relatedness x group interaction ($F(1,66) = 1.26$; $p = .27$; $\eta^2_p = .02$). Importantly, there was a significant double interaction between relatedness at retrieval and group ($F(1,66) = 9.88$; $p < .01$; $\eta^2_p = .13$) characterized, in older adults, by worse discrimination performance when pairs were recombined as related than when pairs were recombined as unrelated ($mean_{recombined\ related} = 0.98$, SD = 0.78; $mean_{recombined\ unrelated} = 1.53$, SD = 0.83; Bonferroni, $p < .001$), and a larger age effect on associative memory performance for related recombinations ($mean_{young} = 1.94$, SD= 0.91; $mean_{older} = 0.98$, SD = 0.78; Bonferroni, $p < .001$; Cohen's d = 1.14) than for unrelated recombinations ($mean_{young} = 2.1$, SD= 0.88; $mean_{older} = 1.53$, SD = 0.83; Bonferroni, $p <$

.05; Cohen's d = 0.67). Finally, there was no interaction between relatedness at encoding, relatedness at retrieval and group ($F(1,66) = 0.01$; $p = .95$; $\eta^2_p = .01$).

<Insert Figure 1 about here>

**Discussion**

Globally, Experiment 1 showed that, for both age groups, in the item test, discrimination performance was better for related than for unrelated items. In the associative test, pairs that were related at encoding and recombinations that were unrelated were discriminated better. In both age groups, the effect size of the increase in performance for unrelated recombinations was particularly important when the pairs were related at encoding and recombined as unrelated (RU), compared with when the pairs were unrelated at encoding and recombined as unrelated (UU), with particularly low FA rates in the RU condition.

Concerning the age-related benefit of semantic relatedness, in this experiment, older adults had poorer performance overall. However, although none of the experimental conditions allowed them to overcome their memory impairment compared with young adults, the group difference in performance was reduced when the pairs were recombined as unrelated, with fewer FAs, regardless of their relatedness at encoding. This only partly supports the transmission deficit hypothesis of NST (MacKay & Burke, 1990), as the age-related benefit in associative memory due to increased number of connections is seen only under specific conditions. Recombining the pairs in an unrelated fashion therefore seems to be a facilitating factor in older adults' associative deficit. These results do not replicate any of the previous studies, since they suggest that (1) relatedness at encoding is not a key-factor by itself in improving older adults' associative memory, contrary to the results shown by Naveh-Benjamin et al. (2003); (2) not all changes in prior knowledge support from encoding to recombination help older adults to improve their associative memory (see our

UR condition), contrary to most past studies that showed that a change in prior knowledge support is a key-factor for older adults to benefit from prior knowledge in associative memory (Fine et al., 2018; Gutchess & Park, 2009; Patterson et al., 2009; Peterson et al., 2017); and (3) older adults' associative memory performance is better when recombinations are unrelated, and this whatever the prior knowledge support at encoding, compared with when recombinations are related, contrary to Mohanty et al.'s (2016) study that showed that older adults only benefitted from prior knowledge in associative memory when it was present at encoding but not at retrieval. The next experiment manipulated categorically-related pairs only in order to further explore the impact of varying the degree of absolute familiarity of the study pairs and recombinations on associative memory, in line with the SAC model (Reder et al., 2007). Thus, in Experiment 2, we implemented a very similar experimental manipulation as in Experiment 1, but instead of manipulating semantic relatedness from encoding to recombination at retrieval, we manipulated the frequency of categorically-related associations from encoding to recombination at retrieval.

## Experiment 2

### Methods

**Participants.** Number of participants recruited in each group was determined by power analyses using G*Power software v3 (Faul, Erdfelder, Lang, & Buchner, 2007) for a 0.95 power based on previous studies' effect sizes with similar design (effect size d = 0.86). Thirty young adults and 30 healthy older adults participated in the experiment. Demographic information are presented in Table 2. All participants were recruited from the local community and were fluent French speakers, with normal or corrected-to-normal vision and hearing and no history of neurological or psychiatric disorders. None of the older adults evidenced any sign of cognitive decline according to the Montreal Cognitive Assessment test (MoCA, Nasreddine et al., 2005).

Young and older adults were matched for years of education ($t(58) = 0.89$; $p = .38$), On the WAIS-III Vocabulary test (/66), older adults displayed better semantic knowledge than young adults ($t(58) = 2.06$; $p < .05$). The study was approved by the Ethics Committee of the Faculty of Psychology of the University of Liège. One young and two older participants were excluded from further analyses due to chance-level performance in at least three of the four conditions of the task, suggesting that they may have misunderstood the task.

**Materials.** One hundred sixty-eight words from 14 categories (7 living and 7 non-living) were selected from a discrete association task that we ran as pilot study in order to develop our materials. In this association task, 480 participants of all ages (mean age = 26.2 years; SD = 11.24; range = 16-72) and education were asked to produce one categorical associate for each target word. There was a total of 208 target words. Subjects who participated to this pilot study did not take part to the main experiment. We obtained a mean of 114.45 productions by target word (SD = 6.98; range: 71–130). We calculated the frequency of each association (target-associate) produced, as the number of productions of the associate in response to a given target word divided by the total number of productions for the given target word. We then selected the 168 associations with the highest (mean = 0.19; SD = .17) and the lowest (mean = 0.03; SD = .01) production frequencies available and assigned them to the high-frequency (HF) and low-frequency (LF) conditions, respectively (for the low-frequency pairs, we excluded all associates with a production frequency ≤ .01). A non-parametric Mann-Whitney U-test confirmed that there was a significant difference in frequency between HF and LF pairs ($U = 5.5$; $p < .001$). Moreover, when separating respondents across three age groups (young (16-35years old), middle-age (36-55years old) and older (56-72years old)), the production frequencies for HF and LF pairs were similar across age groups and the difference between HF and LF pairs remained in each group separately[ii]. The pairs were selected and organized in such a way that each word belonged to two pairs: two HF pairs, two LF pairs, or one HF and one LF pair (see Table 5 for an example of the design). Each word pair was displayed in only one of its configurations at encoding, and in only one (the same or a recombined configuration) at retrieval. In this way, we built four versions of the task to counterbalance the materials across conditions and participants. However, due to the limited number of words that belonged to two pairs that happened to be either HF or LF, full counterbalancing of all words across all conditions was not possible.

<Insert Table 5 about here>

**Procedure.** The task was completed individually by each participant on a laptop computer using E-Prime 2.0. All participants signed an informed consent form. Two study-test cycles were completed with a short break (2 minutes) in between. This was done to avoid fatigue effects due to the length of the list. Before starting the study phase, participants were instructed to study the associations between the words. For each cycle, forty-two pairs[iii] were encoded at a rate of 4 seconds each, including 21 HF pairs and 21 LF pairs, with a 500-ms blank screen and a 500-ms fixation cross between trials. The order of presentation of the study pairs was randomized. The study phase was followed by a 5-minute distracting phase filled with mental calculations. Subsequently, participants took part in an associative recognition test, in which 42 pairs were presented: 7 of the HF pairs and 7 of the LF pairs were presented in the same configuration as during encoding (HF-intact and LF-intact, respectively); 7 of the HF pairs were recombined into other HF pairs (HF-recombined HF; HF-HF); and the last 7 HF pairs were recombined into LF pairs (HF-recombined LF; HF-LF); likewise, 7 of the LF pairs were recombined into other LF pairs (LF-recombined LF; LF-LF); and the last 7 LF pairs were recombined into HF pairs (LF-recombined HF; LF-HF). For each pair presented, participants had to decide whether it was intact or recombined. Participants were told in advance that there were twice as many recombined as intact pairs in order to avoid a response bias due to this imbalance. The recognition test was self-paced. The order of presentation of the two study-test cycles was counterbalanced across participants.

**Data analyses.** Results from the two study-tests cycles were merged for the analyses. Data were analyzed using mixed ANOVAs and follow-up tests were run using Bonferroni post-hoc tests in Statistica, with an alpha level of .05.

## Results

The hit and FA rates and *d'* measures across groups and conditions are displayed in Table 6. We conducted a mixed ANOVA to investigate the effect of frequency at encoding on the hit rates across the two groups. It revealed a main effect of frequency (F(1,55) = 9.05; $p < .01$; $\eta^2_p$ = .14), with a higher hit rate for HF pairs than LF pairs. There was no difference in hit rates across groups (F(1,55) = 1.68; $p = .2$; $\eta^2_p$ = .03), and no interaction between frequency and group (F(1,55) = 2.22; $p = .14$; $\eta^2_p$ = .04).

A mixed ANOVA on the FA rates for recombined pairs across groups and encoding (HF versus LF) and retrieval (HF versus LF recombinations) conditions revealed a main effect of frequency at encoding (F(1,55) = 34.16; $p < .001$; $\eta^2_p$ = .38), with a higher FA rate for pairs that were LF at encoding; a main effect of frequency at retrieval (F(1,55) = 8.95; $p < .01$; $\eta^2_p$ = .14), with a higher FA rate for HF recombinations; and a main effect of group (F(1,55) = 24.01; $p < .001$; $\eta^2_p$ = .3), with a higher FA rate for older adults than younger ones. There was no encoding frequency x recombination frequency interaction (F(1,55) = 0.95; $p = .33$; $\eta^2_p$ = .02); no encoding frequency x group interaction (F(1,55) = 0.01; $p = .92$; $\eta^2_p$ = .01); and no recombination frequency x group interaction (F(1,55) = 0.04; $p = .84$; $\eta^2_p$ = .01). However, there was a significant triple interaction between encoding frequency, recombination frequency, and group ($F(1,55) = 10.06$; $p < .01$; $\eta^2_p = .15$). A Bonferroni post hoc test showed that older adults displayed higher FA rates than young adults only for recombined pairs in the HF-HF (Bonferroni, $p < .01$) and LF-LF (Bonferroni, $p < .01$) conditions, while there was no group difference in the HF-LF (Bonferroni, $p = .37$) and in the LF-HF (Bonferroni, $p = .55$) conditions. Parsing the interaction in a different way, the post hoc test showed, in young adults, that the LF-HF condition triggered significantly more false alarms than the HF-HF (Bonferroni, $p < .01$) and the HF-LF (Bonferroni, $p < .001$) conditions, while the other conditions all displayed similar FA rates (Bonferroni, all *p*s = 1.00). In older adults, the HF-LF condition triggered significantly fewer FAs than the other conditions (Bonferroni, $p < .05$), all of which displayed similar FA rates (Bonferroni, all *p*s = 1.00).

<Insert Table 6 about here>

We calculated four discrimination performance indices (*d'*): (a) distribution of hit rates for intact HF pairs – distribution of FA rates for HF-HF recombined pairs (i.e., HF pairs at encoding that were recombined into other HF pairs at retrieval; *d'* HF-HF); (b) distribution of hit rates for intact HF pairs – distribution of FA rates for HF-LF recombined pairs (*d'* HF-LF); (c) distribution of hit rates for intact LF pairs – distribution of FA rates for LF-HF recombined pairs (*d'* LF-HF); and (d) distribution of hit rates for intact LF pairs – distribution of FA rates for LF-LF recombined pairs (*d'* LF-LF). *d'* scores for each group and condition are displayed in Figure 2. The analysis revealed a main effect of frequency at encoding on discrimination performance ($F(1,55) = 34.65$; $p < .001$; $\eta^2_p = .39$), with better *d'* when the pairs were HF at encoding. There was also a main effect of frequency at retrieval ($F(1,55) = 9.67$; $p < .01$; $\eta^2_p = .15$), with better *d'* when the recombined pairs were LF; and a main effect of group ($F(1,55) = 5.78$; $p < .05$; $\eta^2_p = .09$), with better performance by young than older adults. There was no encoding frequency x retrieval frequency interaction ($F(1,55) = 2.12$; $p = .15$; $\eta^2_p = .04$); no encoding frequency x group interaction ($F(1,55) = 1.17$; $p = .28$; $\eta^2_p = .02$); and no retrieval frequency x group interaction ($F(1,55) = 0.02$; $p = .9$; $\eta^2_p = .01$); but there was a significant triple interaction between frequency at encoding, frequency of the recombinations at retrieval, and group ($F(1,55) = 9.73$; $p < .01$; $\eta^2_p = .15$). A post hoc test showed that, for each condition taken separately, *d'* scores did not differ between young and older adults, suggesting that the main effect of group might have been driven by the accumulation of small but non-significant group differences across conditions, possibly due to the small number of items per condition. However, young adults performed worse in the LF-HF condition than in all other conditions ($mean_{LF\text{-}HF} = 1.05$, SD = 0.9; Bonferroni, $p < .001$), for which there was no performance difference ($mean_{HF\text{-}HF} = 1.53$, SD = 0.83; $mean_{HF\text{-}LF} = 1.6$, SD = 0.87; $mean_{LF\text{-}LF} = 1.29$, SD = 0.75; Bonferroni, all *p*s = 1.00). Conversely, older adults performed worse in both the LF-HF and LF-LF conditions ($mean_{LF\text{-}HF} = 0.68$, SD = 0.7; $M_{LF\text{-}LF} = 0.62$, SD = 0.68; Bonferroni, $p = 1.00$) than in the HF-HF condition ($mean_{HF\text{-}HF} = 1.02$, SD = 0.66; Bonferroni, $p < .05$), in which in turn they performed worse than in the HF-LF condition ($mean_{HF\text{-}LF} = 1.43$, SD = 0.9; Bonferroni, $p < .01$).

<Insert Figure 2 about here>

**Discussion**

In this experiment, we showed that the frequency of an association, deemed to reflect the level of pre-experimental familiarity, influences associative memory discrimination: high frequency at encoding induces a higher hit rate and lower FA rate than low frequency at encoding. On the other hand, high frequency recombinations increase FA rates. Thus, globally, associations of high frequency at encoding and associations of low frequency once recombined lead to better memory discrimination performance. As for the effect of age on associative memory, older adults performed globally more poorly than young adults across all conditions, even though the age effect disappeared when each individual condition was taken separately, and although some conditions seem to have been more favorable than others in improving their performance. Indeed, older adults performed better in the HF-LF condition than in all other conditions, with a lower FA rate, equivalent to that observed in young adults.

## General Discussion

In this study, we intended to delineate the conditions in which older adults benefit from semantic relatedness in associative memory, and those in which any age-related associative memory benefit induced by semantic relatedness is counteracted, possibly due to the high familiarity of the lures associated with impaired strategic retrieval processes. To do so, we manipulated the semantic relatedness within associations at encoding and recombination in Experiment 1, and the frequency of categorically-related associations at encoding and recombination in Experiment 2. We hypothesized that related recombinations (Experiment 1) and those with high association frequency (Experiment 2) would have a high level of absolute familiarity that would induce confusion and interfere with associative discrimination, particularly in older adults, and especially when the encoding conditions prevent semantic memory from providing much support to associative memory, such as for unrelated (Experiment 1) or low frequency (Experiment 2) associations at encoding.

The main findings were that associations that match prior semantic knowledge during encoding, such as semantically related associations (Experiment 1) and, within those, highly frequent associations (Experiment 2), are better recognized, with higher hit rates and lower false alarm rates, than associations that are less congruent with our prior knowledge. We also showed that word pair recombinations with high absolute familiarity – namely, those associated with prior semantic knowledge – tend to hinder associative discrimination by increasing FA rates. More interestingly, we showed that these two factors together are able to modulate associative discrimination to a great extent. Indeed, when participants were presented with relatively arbitrary associations at encoding and subsequently had to discriminate between those and highly familiar lures, we tended to observe worse associative memory performance. Conversely, if participants were presented at encoding with associations that closely matched their semantic knowledge, and subsequently had to discriminate between those and less familiar recombinations, we observed better associative memory performance. This was true across both experiments and both age groups.

With regard to the effect of age on associative memory, we obtained quite consistent results across our two experiments. We showed a modulation of older adults' associative memory performance as well as of the age differences in associative memory depending on the experimental condition. Indeed, some conditions were characterized by smaller age effects than others, suggesting that they could have facilitated older adults' associative discrimination, coherent with some of our hypotheses. Experiment 1 demonstrated that the age-related deficit was reduced, although not completely attenuated, when the recombinations were unrelated, regardless of their relatedness at encoding. This better performance in older adults was characterized by lower false alarm rates, probably due to the lower absolute familiarity of the recombinations. This result thus does not corroborate previous studies showing an age-related benefit of semantic relatedness at encoding (e.g., Naveh-Benjamin et al., 2003). In fact, studies in aging have particularly put the emphasis on the relatedness of associations *at encoding*, with less attention paid to the relatedness of the recombinations at retrieval (Naveh-Benjamin et al., 2003). Yet, this seems to be a crucial point to keep in mind. Studies from Fine et al. (2018), Gutchess and Park (2009), Mohanty et al.

(2016), Patterson et al. (2009) or Peterson et al. (2017) explored this effect of a change in prior knowledge support from encoding to recombination and showed an age-related benefit only when there was a change of prior knowledge support from encoding to retrieval. Our result go beyond this, demonstrating that any change in prior knowledge support does not induce improvement in associative memory, but only a change in the sense of a presence of prior knowledge at encoding, but not in the recombination, does. As for Experiment 2, it showed no age difference in associative memory performance in any of its conditions taken separately, although older adults performed globally poorer than younger ones, with more false alarms, particularly in the absence of a change in associative frequency from encoding to recombination. Some interesting effects were, however, found when observing the older adults' different performance across conditions. This group performed better when HF associations were used at encoding, thus matching their preexisting knowledge very closely, and performed even better when, additionally, LF recombinations were used at retrieval, inducing lower false alarm rates, probably because they were less familiar than the studied associations (HF-LF condition). Young adults, on the other hand, only performed worse in the LF-HF condition compared with all other conditions.

There was also some differences across the two experiments' results that are worth noting. First, concerning the pattern of age differences in the false alarm rates, the results for the study pairs that were unfamiliar or weakly familiar and recombined into more familiar pairs are not congruent across experiment 1 and 2. Indeed, results revealed higher false alarms in older compared with young adults in Experiment 1 (UR) but not in Experiment 2 (LF-HF). Also, it appears clearly across our two experiments that the condition best performed (in terms of *d'*) by older adults is the one in which study pairs are highly familiar and are recombined into pairs with low or no familiarity, and that the condition worst performed is the one in which study pairs are only weakly or not related at all, and are recombined into highly related pairs. This is because the former condition allows the most reliable use of familiarity for preexisting concept nodes, without the need of recollecting the associated episode node to reject familiar lures (MacKay & Burke, 1990; Patterson et al., 2009; Reder et al., 2007). But the intermediate conditions, in which no change in congruency occurs from encoding to recombination lead to more discrepant results. In Experiment 1, when the study pairs were familiar and were recombined into pairs that were familiar as well (RR), performance was as low as when no support from relatedness was present at encoding (UR), while in Experiment 2 (HF-HF), performance was better (relative to LF-HF), although not optimal. Conversely, unrelated pairs that were recombined into other unrelated pairs in Experiment 1 (UU) led to better performance than when recombined into related pairs, with no increase in false alarms compared with young, while such manipulation with low frequency pairs in Experiment 2 (LF-LF) did not help improving performance, due to increased false alarms compared with young. The reasons for this divergence in findings across studies are not clear. Such discrepancies might be due to the differences across the two experiments such as the different number of pairs at encoding and at retrieval across the two experiments, different presentation times at encoding, the presence or absence of an item test, or the different proportions of intact and recombined pairs during associative recognition. Still, in our view, the main difference across the two experiments to explain the discrepancies between the findings is the type of relatedness manipulated. Indeed, Experiment 1 manipulated the presence versus the absence of semantic relatedness within associations, while Experiment 2 manipulated, within pairs that were all categorically-related, the frequency of association. Thus, in Experiment 2, all pairs had some level of pre-experimental familiarity, while in Experiment 1, some pairs were pre-experimentally familiar, and some were not. So, the different conditions were variable in terms of the difference in the strength of familiarity between study and test, so that the level of absolute familiarity of the supposedly least familiar lures was different across the two tasks and could have induced differences in the availability of cues for strategic retrieval or in response criterion.

Overall, still, the results fit quite well with our initial hypotheses. We hypothesized that (1) impaired recollection and retrieval strategies such as recall-to-reject, together with (2) increased reliance in familiarity and (3) decreased memory monitoring processes, would be accounting factors for the associative deficit, which could be alleviated by promoting reliable use of familiarity through encoding relying on prior knowledge and favoring retrieval strategies at recognition. This is what our results tend to suggest, since they show that older adults' associative memory can be improved by the presence of semantic relatedness under specific conditions only. Increased reliance on familiarity can explain why older adults take advantage of the fact that associations are highly congruent with prior knowledge at encoding (as congruent information induces a feeling of familiarity), but also produce more false alarms to recombined pairs bearing pre-experimental familiarity. The rejection of these recombined pairs necessitate intact recollection abilities and accurate memory monitoring to detect the source of the feeling of familiarity. In contrast, when recombinations were of weaker congruency than study pairs, the demands in terms of recollection and monitoring processes were greatly decreased and the loss of semantic relatedness facilitates strategic rejection, so that decline of these abilities in aging was no longer a problem. Such combined circumstances seem to be helpful to older adults by reducing their false associative recognitions, which are thought to be characteristic of their associative deficit (Kilb & Naveh-Benjamin, 2011). Thus, relatedness at encoding alone does not actually seem to be the most critical condition for improving older adults' associative memory; instead, both relatedness at encoding *and* an absence of relatedness of the recombined lures may be what helps to improve older adults' associative performance, by enabling and supporting strategic encoding and retrieval (by allowing a greater reliance on familiarity while promoting strategic retrieval processes).

These results are particularly interesting in light of the current associative memory literature. Semantic relatedness within pairs of words has been considered as a case of passive unitization strategy, which increases the contribution of familiarity to recognition memory (Greve, van Rossum, & Donaldson, 2007; Tibon et al., 2014). For this reason and because of impaired recollection in aging, otherwise necessary for associative recognition, as opposed to preserved familiarity, unitization has long been thought to be able to attenuate older adults' associative memory deficit. However, the literature has also pointed out to some possible pitfall of unitization induced by semantic relatedness. Manipulating semantic relatedness by supplying prior knowledge support at encoding probably increases gist-based processing in older adults particularly (Koutstaal, Schacter, Galluccio, & Stofer, 1999), with a decrease in item-specific information processing, and thereby a less distinctive associative memory trace. Moreover, strategic retrieval and monitoring processes being impaired in aging (Devitt & Schacter, 2016), increases in familiarity, together with less distinctive memory traces, could be a double-edged sword leading to increased false recognitions (Reder et al., 2007). Thereby, and based on the current results, we argue that semantic relatedness *per se* is not sufficient to improve older adults' associative memory, and that only lures with a distinct gist from, and less familiarity than encoded pairs, help older adults for associative discrimination by promoting strategic retrieval processes. In contrast, lures with a similar gist (category membership) and level of absolute familiarity prevent older adults from overcoming lure familiarity and lead to increased conjunctive or gist-based familiarity-driven false recognitions. Of note, an interpretation in terms of unitization encounters the caveat that reasoning can be circular if one considers that there is unitization because associative memory and/or familiarity-based performance is enhanced (Parks & Yonelinas, 2015; Pilgrim, Murray, & Donaldson, 2012). Independent evidence of unitization would be required, such as the fact that individual items from the associations are more poorly remembered or induced less familiarity-related neural activity than the integrated associations (Pilgrim et al., 2012). Very few studies on unitization have been able to demonstrate that. As the current study did not measure single word memory, there was no independent measure of unitization. So the possibility that the benefit of semantic relatedness in associative memory is a case of unitization remains to be proven. Thus, for now, a mechanistic interpretation of the pattern of findings in terms of absolute/relative familiarity and strategic retrieval strategies is favored.

This finding sheds some light on most of the current studies on the topic, and has the potential to explain some discrepancies in the literature exploring the age-related associative benefit of semantic relatedness. Importantly, most of the studies that actually showed an attenuation of the age-related associative deficit when using prior knowledge actually used pairs that were highly coherent with preexisting semantic knowledge at encoding, and that were subsequently recombined with a change (usually, although not always, a reduction) in the level of prior knowledge support at retrieval (Cooper & Odegard, 2012; Fine et al., 2018; Mohanty et al., 2016; Patterson et al., 2009; Peterson et al., 2017; this also applies to the study by Zheng et al., 2015, to some extent, in the sense that compound word pairs at encoding were recombined as other compound word pairs, but using items from pairs that were non-compound at encoding, and vice versa). In a similar vein, the study by Naveh-Benjamin et al. (2003) changed the type of semantic link (categorical, thematic or perceptual relationship) between the related associations from study to recombination. Thus, it might be possible that the recombination of a categorical word pair (e.g., *salad – carrot*) at encoding into a thematic relationship (e.g., *salad – garden*) at retrieval provided distinctive cues to help older adults with their memory decisions. Conversely, studies that did not show any age-related benefit of prior knowledge did not apply any change in the relatedness or plausibility or congruency of the association, nor did they reduce the level of prior knowledge support from encoding to recombination (Bridger et al., 2017; Cooper & Odegard, 2012; Delhaye & Bastin, 2018; Mohanty et al., 2016; Patterson et al., 2009; Peterson et al., 2017).

However, a few studies did not follow this tendency. For instance, in the study by Delhaye et al. (2017), there was a switch in relatedness from encoding to recombination, but the study did not find evidence of the expected age-related benefit. Conversely, the study by Ahmad et al. (2015) did not reduce the level of prior knowledge support from encoding to recombination, but it still showed an age-related benefit from unitization. Finally, Smyth and Naveh-Benjamin (2018) also kept the level of prior knowledge support equivalent between encoding and recombination but still showed an age-related improvement in associative recognition for linguistically congruent adjective-noun associations. Possibly, differences in the materials used contributed to this discrepancy by inducing different levels of strength of the semantic relatedness. This was the case, for instance, in the study of Smyth and Naveh-Benjamin, by manipulating integrative relations (when two unrelated words can be linked to form a coherent representation). Thus, further investigation is still needed to shed more light on these special cases.

In conclusion, this study showed that manipulating semantic relatedness between to-be-remembered associations at encoding, and, more importantly, once recombined, can have a great influence on associative recognition memory. Importantly, this study showed the optimal conditions for older adults to benefit from semantic relatedness in memory, which consist in a change of prior knowledge support between encoding and recombinations at retrieval, but only in the sense of a decrease of prior knowledge support. Such manipulation would allow older adults to use relatedness at encoding as a distinctive cue for retrieval, additional to the associative episodic memory itself, and would thereby allow them to implement strategic retrieval processes on this basis and to overcome lure familiarity. This result finally allows to explain the current discrepancies in the literature concerning the impact of semantic relatedness in associative memory in aging.

References

Ahmad, F. N., Fernandes, M., & Hockley, W. E. (2015). Improving associative memory in older adults with unitization. *Aging, Neuropsychology, and Cognition*, 1–21. https://doi.org/10.1080/13825585.2014.980216

Badham, S. P., Estes, Z., & Maylor, E. A. (2012). Integrative and semantic relations equally alleviate age-related associative memory deficits. *Psychology and Aging*, *27*(1), 141.

Badham, S. P., Hay, M., Foxon, N., Kaur, K., & Maylor, E. A. (2015). When does prior knowledge disproportionately benefit older adults' memory? *Aging, Neuropsychology, and Cognition*, 1–28. https://doi.org/10.1080/13825585.2015.1099607

Badham, S. P., & Maylor, E. A. (2015). What you know can influence what you are going to know (especially for older adults). *Psychonomic Bulletin & Review*, *22*(1), 141–146. https://doi.org/10.3758/s13423-014-0672-8

Badham, S. P., & Maylor, E. A. (2016). Antimnemonic effects of schemas in young and older adults. *Aging, Neuropsychology, and Cognition*, *23*(1), 78–102. https://doi.org/10.1080/13825585.2015.1048774

Bastin, C., Diana, R. A., Simon, J., Collette, F., Yonelinas, A. P., & Salmon, E. (2013). Associative memory in aging: The effect of unitization on source memory. *Psychology and Aging*, *28*(1), 275–283. https://doi.org/10.1037/a0031566

Brainerd, C. J., & Reyna, V. F. (2002). Fuzzy-trace theory and false memory. *Current Directions in Psychological Science*, *11*(5), 164–169.

Bridger, E. K., Kursawe, A.-L., Bader, R., Tibon, R., Gronau, N., Levy, D. A., & Mecklinger, A. (2017). Age effects on associative memory for novel picture pairings. *Brain Research*, *1664*, 102–115. https://doi.org/10.1016/j.brainres.2017.03.031

Buchler, N. E. G., & Reder, L. M. (2007). Modeling age-related memory deficits: A two-parameter solution. *Psychology and Aging*, *22*(1), 104–121. https://doi.org/10.1037/0882-7974.22.1.104

Castel, A. D. (2005). Memory for Grocery Prices in Younger and Older Adults: The Role of Schematic Support. *Psychology and Aging*, *20*(4), 718–721. https://doi.org/10.1037/0882-7974.20.4.718

Castel, A. D., McGillivray, S., & Worden, K. M. (2013). Back to the Future: Past and Future Era-Based Schematic Support. *Psychology and Aging*, *28*(4), 996–1003.

Coane, J. H., Balota, D. A., Dolan, P. O., & Jacoby, L. L. (2011). Not all sources of familiarity are created equal: the case of word frequency and repetition in episodic recognition. *Memory & Cognition*, *39*(5), 791–805. https://doi.org/10.3758/s13421-010-0069-5

Cohn, M., Emrich, S. M., & Moscovitch, M. (2008). Age-related deficits in associative memory: The influence of impaired strategic retrieval. *Psychology and Aging*, *23*(1), 93–103. https://doi.org/10.1037/0882-7974.23.1.93

Cooper, C. M., & Odegard, T. N. (2012). Influence of recollection and plausibility on age-related deficits in associative memory. *Memory*, *20*(1), 28–36. https://doi.org/10.1080/09658211.2011.630671

D'Angelo, M. C., Noly-Gandon, A., Kacollja, A., Barense, M. D., & Ryan, J. D. (2017). Breaking down unitization: Is the whole greater than the sum of its parts? *Memory & Cognition*, *45*(8), 1306–1318. https://doi.org/10.3758/s13421-017-0736-x

D'Angelo, M. C., Smith, V. M., Kacollja, A., Zhang, F., Binns, M. A., Barense, M. D., & Ryan, J. D. (2016). The effectiveness of unitization in mitigating age-related relational learning impairments depends on existing cognitive status. *Aging, Neuropsychology, and Cognition, 23*(6), 667–690. https://doi.org/10.1080/13825585.2016.1158235

Delhaye, E., & Bastin, C. (2018). The impact of aging on associative memory for preexisting unitized associations. *Aging, Neuropsychology, and Cognition*, 1–29. https://doi.org/10.1080/13825585.2016.1263725

Delhaye, E., Tibon, R., Gronau, N., Levy, D. A., & Bastin, C. (2017). Misrecollection prevents older adults from benefitting from semantic relatedness of the memoranda in associative memory. *Aging, Neuropsychology, and Cognition*, 1–21. https://doi.org/10.1080/13825585.2017.1358351

Deltour, J. (1993). *Echelle de vocabulaire de Mill Hill de J.C. Raven. Adaptation francaise et normes comparées du Mill Hill et du Standard Progressive Matrices (PM 38). Manuel.* (Editions l'Application des Techniques Modernes.). Braine-le-Château.

Devitt, A. L., & Schacter, D. L. (2016). False memories with age: Neural and cognitive underpinnings. *Neuropsychologia*, *91*, 346–359. https://doi.org/10.1016/j.neuropsychologia.2016.08.030

Fandakova, Y., Shing, Y. L., & Lindenberger, U. (2013). High-confidence memory errors in old age: The roles of monitoring and binding processes. *Memory*, *21*(6), 732–750. https://doi.org/10.1080/09658211.2012.756038

Fine, H. C., Shing, Y. L., & Naveh-Benjamin, M. (2018). Effects of changes in schematic support and of item repetition on age-related associative memory deficits: Theoretically-driven empirical attempts to reduce older adults' high false alarm rate. *Psychology and Aging*, *33*(1), 57–73. https://doi.org/10.1037/pag0000211

Graf, P., & Schacter, D. L. (1989). Unitization and grouping mediate dissociations in memory for new associations. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *15*(5), 930.

Greve, A., van Rossum, M. C. W., & Donaldson, D. I. (2007). Investigating the functional interaction between semantic and episodic memory: Convergent behavioral and electrophysiological evidence for the role of familiarity. *NeuroImage*, *34*(2), 801–814. https://doi.org/10.1016/j.neuroimage.2006.07.043

Gutchess, A. H., & Park, D. C. (2009). Effects of ageing on associative memory for related and unrelated pictures. *European Journal of Cognitive Psychology*, *21*(2–3), 235–254. https://doi.org/10.1080/09541440802257274

Jäger, T., Mecklinger, A., & Kliegel, M. (2010). Associative Recognition Memory for Faces: More Pronounced Age-Related Impairments in Binding Intra- than Inter-Item Associations. *Experimental Aging Research*, *36*(2), 123–139. https://doi.org/10.1080/03610731003613391

James, L. E., Fogler, K. A., & Tauber, S. K. (2008). Recognition memory measures yield disproportionate effects of aging on learning face-name associations. *Psychology and Aging*, *23*(3), 657–664. https://doi.org/10.1037/a0013008

Kilb, A., & Naveh-Benjamin, M. (2011). The effects of pure pair repetition on younger and older adults' associative memory. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *37*(3), 706–719. https://doi.org/10.1037/a0022525

Koen, J. D., & Yonelinas, A. P. (2014). Recollection, not familiarity, decreases in healthy ageing: Converging evidence from four estimation methods. *Memory*, 1–14. https://doi.org/10.1080/09658211.2014.985590

Koutstaal, W., Schacter, D. L., Galluccio, L., & Stofer, K. A. (1999). Reducing gist-based false recognition in older adults: Encoding and retrieval manipulations. *Psychology and Aging*, *14*(2), 220.

Mackay, D. G. (1987). The Functions of Mental Nodes. In *The Organization of Perception and Action* (Cognitive Science Series. Springer, pp. 126–140). New York, NY.

Macmillan, N. A., & Creelman, C. D. (2005). *Detection theory: A user's guide.* Mahwah, N.J.: Lawrence Erlbaum Associates.

McGillivray, S., & Castel, A. D. (2010). Memory for age–face associations in younger and older adults: The role of generation and schematic support. *Psychology and Aging*, *25*(4), 822–832. https://doi.org/10.1037/a0021044

Memel, M., & Ryan, L. (2017). Visual integration enhances associative memory equally for young and older adults without reducing hippocampal encoding activation. *Neuropsychologia*, *100*, 195–206. https://doi.org/10.1016/j.neuropsychologia.2017.04.031

Mohanty, P. (Pam), Naveh-Benjamin, M., & Ratneshwar, S. (2016). Beneficial effects of semantic memory support on older adults' episodic memory: Differential patterns of support of item and associative information. *Psychology and Aging*, *31*(1), 25–36. https://doi.org/10.1037/pag0000059

Naveh-Benjamin, M. (2000). Adult age differences in memory performance: Tests of an associative deficit hypothesis. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *26*(5), 1170–1187. https://doi.org/10.1037//0278-7393.26.5.1170

Naveh-Benjamin, M., Brav, T. K., & Levy, O. (2007). The associative memory deficit of older adults: The role of strategy utilization. *Psychology and Aging*, *22*(1), 202–208. https://doi.org/10.1037/0882-7974.22.1.202

Naveh-Benjamin, M., Hussain, Z., Guez, J., & Bar-On, M. (2003). Adult age differences in episodic memory: Further support for an associative-deficit hypothesis. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *29*(5), 826–837. https://doi.org/10.1037/0278-7393.29.5.826

Ofen, N., & Shing, Y. L. (2013). From perception to memory: Changes in memory systems across the lifespan. *Neuroscience & Biobehavioral Reviews*, *37*(9), 2258–2267. https://doi.org/10.1016/j.neubiorev.2013.04.006

Ostreicher, M. L., Moses, S. N., Rosenbaum, R. S., & Ryan, J. D. (2010). Prior Experience Supports New Learning of Relations in Aging. *The Journals of Gerontology Series B: Psychological Sciences and Social Sciences*, *65B*(1), 32–41. https://doi.org/10.1093/geronb/gbp081

Parks, C. M., & Yonelinas, A. P. (2015). The Importance of Unitization for Familiarity-Based Learning. *Journal of Experimental Psychology: Learning, Memory, and Cognition*. https://doi.org/10.1037/xlm0000068

Patterson, M. M., Light, L. L., Van Ocker, J. C., & Olfman, D. (2009). Discriminating Semantic from Episodic Relatedness in Young and Older Adults. *Aging, Neuropsychology, and Cognition*, *16*(5), 535–562. https://doi.org/10.1080/13825580902866638

Pedraza, O., Lucas, J. A., Smith, G. E., Petersen, R. C., Graff-Radford, N. R., & Ivnik, R. J. (2010). Robust and Expanded Norms for the Dementia Rating Scale. *Archives of Clinical Neuropsychology*, *25*(5), 347–358. https://doi.org/10.1093/arclin/acq030

Peterson, D. J., Schmidt, N. E., & Naveh-Benjamin, M. (2017). The role of schematic support in age-related associative deficits in short-term and long-term memory. *Journal of Memory and Language*, *92*, 79–97. https://doi.org/10.1016/j.jml.2016.05.007

Pilgrim, L. K., Murray, J. G., & Donaldson, D. I. (2012). Characterizing episodic memory retrieval: Electrophysiological evidence for diminished familiarity following unitization. *Journal of Cognitive Neuroscience*, *24*(8), 1671–1681.

Reder, L. M., Paynter, C., Diana, R. A., Ngiam, J., & Dickison, D. (2007). Experience is a Double-Edged Sword: A Computational Model of The Encoding/Retrieval Trade-Off With Familiarity. In *Psychology of Learning and Motivation* (Vol. 48, pp. 271–312). Elsevier. https://doi.org/10.1016/S0079-7421(07)48007-0

Ryan, J. D., D’Angelo, M. C., Kamino, D., Ostreicher, M., Moses, S. N., & Rosenbaum, R. S. (2016). Relational learning and transitive expression in aging and amnesia: RELATIONAL LEARNING AND TRANSITIVE EXPRESSION. *Hippocampus*, *26*(2), 170–184. https://doi.org/10.1002/hipo.22501

Smyth, A. C., & Naveh-Benjamin, M. (2018). Existing knowledge of linguistic structure mitigates associative memory deficits in older adults. *Experimental Aging Research*, *44*(1), 35–47. https://doi.org/10.1080/0361073X.2017.1398517

Tibon, R., Gronau, N., Scheuplein, A.-L., Mecklinger, A., & Levy, D. A. (2014). Associative recognition processes are modulated by the semantic unitizability of memoranda. *Brain and Cognition*, *92*, 19–31. https://doi.org/10.1016/j.bandc.2014.09.009

Umanath, S., & Marsh, E. J. (2014). Understanding how prior knowledge influences memory in older adults. *Perspectives on Psychological Science*, *9*(4), 408–426.

Yonelinas, A. P. (2002). The Nature of Recollection and Familiarity: A Review of 30 Years of Research. *Journal of Memory and Language*, *46*(3), 441–517. https://doi.org/10.1006/jmla.2002.2864

Yonelinas, A. P., Aly, M., Wang, W.-C., & Koen, J. D. (2010). Recollection and familiarity: Examining controversial assumptions and new directions. *Hippocampus, 20*(11), 1178–1194. https://doi.org/10.1002/hipo.20864

Zacks, R. T., Hasher, L., & Li, K. Z. H. (2000). Human memory. In *The handbook of aging and cognition* (pp. 293–357). Mahwah, NJ, US: Lawrence Erlbaum Associates Publishers.

Zheng, Z., Li, J., Xiao, F., Broster, L. S., & Jiang, Y. (2015). Electrophysiological evidence for the effects of unitization on associative recognition memory in older adults. *Neurobiology of Learning and Memory*, *121*, 59–71. https://doi.org/10.1016/j.nlm.2015.03.006

Footnotes

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[i] Here, we draw readers' attention to the fact that, although we show a deficit in item memory as in associative memory in older adults, a mixed ANOVA on the *d'* including the two groups as between-subjects factor, and the two test types and relatedness status at encoding and at retrieval as within-subject factors was qualified by a significant group x test type interaction ($F(1,66) = 7.59$; $p < .01$; $\eta^2_p = .1$) according to which the age effect on performance was significantly greater in the associative test (Bonferroni, $p < .001$, Cohen's d = .82) compared with the item test ($p = .08$, Cohen's d = .54), so that older adults still show an associative memory deficit.

[ii] A 3 (group: young, middle-age, older) x 2 (assigned level of frequency: HF, LF) repeated measures ANOVA with Greenhouse-Geisser correction for sphericity showed a main effect of frequency ($F(1,166)=74.64$, $p < .001$) confirming that pairs assigned to HF versus LF conditions were of significantly different production frequencies, but no main effect of age group ($F(1.63, 270.17)= 0.16$, $p = .8$) and no interaction ($F(1.63, 270.17)= 0.1$, $p = .86$) Mean frequency of production of HF pairs in young = 0.19, SD = .18, middle-age = 0.19, SD = .17 and older participants = 0.19, SD = .21. Mean frequency of production of LF pairs in young = 0.03, SD = .01, middle-age = 0.03, SD = .03 and older participants = 0.03, SD = .06.

[iii] The use of different numbers of stimuli and presentation times in each of the experiments was a result of pilot studies; it was determined so to avoid ceiling effects in the young participants and floor effects in the older ones.