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Recalling the firedog: Individual differences in associative memory for unitized and nonunitized associations among older adults

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Abstract

Memory deficits in aging are characterized by impaired hippocampus-mediated relational binding—the formation of links between items in memory. By reducing reliance on relational binding, unitization of two items into one concept enhances associative recognition among older adults. Can a similar enhancement be obtained when probing memory with recall? This question has yet to be examined, because recall has been assumed to rely predominantly on relational binding. Inspired by recent evidence challenging this assumption, we investigated individual differences in older adults' recall of unitized and nonunitized associations. Compared with successfully aging individuals, older adults with mild memory deficits, typically mediated by the hippocampus, were impaired in recall of paired-associates in a task which relies on relational binding (study: "PLAY–TUNNEL"; test: PLAY–T?). In stark contrast, the two groups showed similar performance when items were unitized into a novel compound word (study: "LOVEGIGGLE"; test: LOVEG?). Thus, boosting nonrelational aspects of recall enhances associative memory among aging individuals with subtle memory impairments to comparable levels as successfully aging older adults.

KEYWORDS
aging, associative memory, hippocampus, individual differences

"[…] our mind is essentially an associating machine."
William James, Talks to Teachers on Psychology and to Students on Some of Life's Ideals

1 | INTRODUCTION

A central feat of human memory—mediated primarily by the hippocampus—is the ability to rapidly form novel associations between two unrelated pieces of information (Davachi, 2006; Eichenbaum, 2003). This capacity is, in fact, the core mechanism driving most of our day-to-day information acquisition, whether we are learning the name of a person we just met, noting where we left our keys, or remembering when a meeting is taking place. Furthermore, the importance of forming associations goes beyond the domain of memory. Processing of associative information has been shown to crucially support a variety of cognitive functions (Rubin, Watson, Duff, & Cohen, 2014), such as decision-making (Wimmer & Shohamy, 2012), creativity (Duff, Kurczek, Rubin, Cohen, & Tranel, 2013), social interactions (Davidson, Drouin, Kwan, Moscovitch, & Rosenbaum, 2012), and even discourse and language use (Kurczek, Brown-Schmidt, & Duff, 2013).

Unfortunately, the capacity to form and retain associations is markedly impaired in aging individuals who suffer from subtle memory impairments. While memory for single items is relatively preserved in these individuals, their associative memory shows substantial impairments (Naveh-Benjamin, 2000; Naveh-Benjamin, Hussain, Guez, & Bar-On, 2003; Old & Naveh-Benjamin, 2008). In part, this impairment is believed to result from deficits in relational binding—the process of "acquiring and maintaining lasting representations regarding relations among distinct items" (Ryan, Moses, Barense, & Rosenbaum, 2013). An abundance of evidence has established that relational binding is mediated by the hippocampus (Davachi, 2006; Olsen et al., 2015; Pertzov et al., 2013; Ranganath, 2010; Ryan, Althoff, Whitlow, & Cohen, 2000; Sadeh, Maril, Bitan, & Goshen-Gottstein, 2012; Sadeh, Maril, & Goshen-Gottstein, 2012; Yonelinas, 2013), and, indeed, deficits in this process are associated with reduction of hippocampal volume, as well as by functional changes in hippocampal activation and connectivity during encoding and retrieval of associative information (Carr et al., 2017; Dennis et al., 2008; Rodrigue, Daugherty, Haacke, & Raz, 2013).

Importantly, however, episodic memory deficits are not a necessary outcome of aging. In fact, there is substantial heterogeneity in the cognitive profiles of older adults, with some individuals showing what is often termed "successful aging," namely performance at the highest end of the scale (e.g., Habib, Nyberg, & Nilsson, 2007; Jorm et al., 1998; Rowe & Kahn, 1987). Thus, a certain proportion of older adults shows no deficits in episodic memory and, therefore, should show spared associative memory performance.

In the current study, we leveraged the heterogeneity in older adults' mnemonic function to investigate associative memory among a sample of community-dwelling older adults with no diagnosed cognitive deficits. Because we were interested in examining variability in mnemonic performance among older adults, we took a similar approach to that reported previously (Leal, Noche, Murray, & Yassa, 2017; Stark, Yassa, Lacy, & Stark, 2013; Stark, Yassa, & Stark, 2010; see also Hughes, Berg, Danziger, Coben, & Martin, 1982; Khan, 2016; Manning & Ducharme, 2010; Morris, 1993) by splitting our sample into two groups according to their memory abilities—henceforth referred to as "High-Performers" and "Low-Performers." The division into the two groups was based on performance in the delayed-recall component of the Montreal Cognitive Assessment (MoCA)—a standard neuropsychological test which is particularly sensitive for detecting even subtle age-related cognitive impairments (Gluhm et al., 2013; Hoops et al., 2009; Markwick, Zamboni, & de Jager, 2012; McLennan, Mathias, Brennan, & Stewart, 2011; Nasreddine et al., 2005; Newsome, Duarte, & Barense, 2012; Newsome, Pun, Smith, Ferber, & Barense, 2013). Importantly, results in the MoCA test are positively correlated with hippocampal volume (O'Shea, Cohen, Porges, Nissim, & Woods, 2016; Ritter, Hawley, Banks, & Miller, 2017). Lower MoCA scores, and specifically in the memory component of the MoCA, are associated with hippocampal atrophy. This test, therefore, provides a useful measure of hippocampus-mediated memory decline. To divide our sample into two groups, we followed similar steps as Stark et al. (2010). The High-Performers group included individuals with a MoCA delayed-recall score which is comparable to that of younger adults—a perfect 5/5 score (Gluhm et al., 2013; Pike, Poulsen, & Woo, 2017; see also Zheng et al., 2018), and the Low-Performers group included all participants with a MoCA delayed-recall score of less than 5 points. Thus, the Low-Performers show only a very subtle impairment in memory performance and do not have any clinical diagnosis of cognitive deficit.

The primary goal of the current study was to examine whether the well-established deficit in recall of novel associations among aging individuals with subtle memory impairment (operationalized as Low-Performers) might be mitigated by using a paradigm that does not tax hippocampus-dependent relational binding to the same extent as standard associative memory tasks. We hypothesized that, as compared to High-Performers, Low-Performers would exhibit lower performance in an associative memory task, which depends on relational binding, in line with the associative memory deficit hypothesis. In contrast, their impairment would be mitigated (and even alleviated to levels comparable to High-Performers) in an associative memory task which does not rely on relational binding.

Evidence accumulated in the past decade has established that associative memory may be supported by nonrelational, item-based processing when the to-be-associated items are unitized into a single item (for a review see Parks & Yonelinas, 2015). When unitized, the two items no longer refer to two individual concepts, but rather to one unified concept. Hence, there is no need to represent the relation between the two items. Thus, unitization reduces (and even eliminates) the reliance on relational processes in associative memory tasks. As such, memory for unitized items may be supported by the nonrelational process of item-familiarity, rather than on recollection of relational information regarding the link between the two items (Parks & Yonelinas, 2015).

A common paradigm in unitization research involves learning novel compound words (e.g., "LAZYTEXT: abbreviations, like 'LOL' = Laughing Out Loud, used in instant messaging"). In the Compound condition, the two items (e.g., LAZY and TEXT) are unitized into a single concept (the new compound word LAZYTEXT). Hence, performance in this condition can rely on item-memory and does not necessitate retrieval of relational information regarding the link between the two items. The Compound condition is compared to standard associative memory tasks, in which each of the two constituent words preserves its meaning (e.g., "He was too LAZY to TEXT his friend to wish him Happy Birthday"). Performance in the standard associative task relies on relational binding to represent the link between the two items (LAZY and TEXT). Studies using this and conceptually similar paradigms have converged on the notion that learning of unitized associations is driven by nonrelational processing. Four lines of evidence have supported this notion.

First, amnesic patients with relational binding deficits presumably induced by hippocampal damage show enhanced performance in a learning task promoting unitization between two items, as compared to a nonunitization condition (Quamme, Yonelinas, & Norman, 2007). Patients with both item-memory and relational binding deficits, whose damage likely extends to regions beyond the hippocampus, do not show such an enhancement. Second, encoding unitized item pairs is associated with blood oxygenation level-dependent activation in the perirhinal cortex, a region involved in processing of single items, rather than relational binding (Haskins, Yonelinas, Quamme, & Ranganath, 2008). Third, familiarity estimates (reflecting nonrelational processing) are greater in unitization conditions, as compared to standard association tasks, which rely on relational binding (Diana, Yonelinas, & Ranganath, 2008; Opitz & Cornell, 2006; Parks & Yonelinas, 2015; Tibon, Vakil, Goldstein, & Levy, 2012). Last, unitization strategies decrease associative memory deficits in older adults (Ahmad, Fernandes, & Hockley, 2015; Zheng, Li, Xiao, Broster, & Jiang, 2015; Zheng, Li, Xiao, Ren, & He, 2016; but see Kamp, Bader, & Mecklinger, 2018).

Despite the converging evidence, there are a number of gaps, which our study addresses. Specifically, none of the previous studies examined older adults' associative memory performance as a function of their cognitive status. Namely, the group of older adults was treated as a homogenous sample, with typical age-related memory impairment. In contrast, in the current study we focus on the heterogeneity in older adults' cognitive status and distinguish between aging individuals with subtle memory impairment (Low-Performers) and those who age successfully (High-Performers).

Most importantly, in all previous studies, memory was probed using recognition tests, usually by having participants distinguish between intact (old) and recombined (new) study-pairs. To our knowledge, no study to date has examined recall of unitized item pairs, which was our goal in this study. The single focus on recognition in previous studies is not surprising considering the common conceptualization of recall as a task relying predominantly on hippocampus-mediated relational binding (Guderian, Brigham, & Mishkin, 2011; Hirst et al., 1986; Humphreys et al., 2010; Yonelinas, 2002). In line with these ideas, previous empirical findings have revealed that performance in tests of recall is disproportionally impaired in populations with memory decline (e.g., Bastin et al., 2004; Hirst et al., 1986; Hirst, Johnson, Phelps, & Volpe, 1988). In the face of this conceptualization, however, research, mostly from recent years, has shown that at times recall may rely less (or not at all) on relational binding and more (or entirely) on item-memory or habit-memory. Such effects have been shown in studies employing various recall paradigms, including free recall (McCabe, Roediger, & Karpicke, 2011; Mickes, Seale-Carlisle, & Wixted, 2013; Sadeh, Moran, & Goshen-Gottstein, 2014; Sadeh, Moran, Stern, & Goshen-Gottstein, 2018; Uner & Roediger, 2018), paired-associates recall (Brainerd, Reyna, & Howe, 2009; Brainerd, Wright, Reyna, & Payne, 2002; Hay & Jacoby, 1996), and category/category plus letter cued recall (Hamilton & Rajaram, 2003; Tulving, 1985). These results raise the exciting notion that by using mnemonic strategies which capitalize on nonrelational processes, individuals with subtle memory impairment may show improved performance in tests of recall. Thus, we hypothesized that unitization at encoding might enhance recall of paired-associates via reducing reliance on relational binding, in the same way as it has been shown to do in recognition.

To test this notion, the current study compared performance of older adults in recall of paired-associates between two encoding conditions. In the Compound condition, participants learned new compound words (e.g., LOVEGIGGLE) by deducing the meaning of the compound word from its use in a sentence ("She tried to hide her affection to the boy, but her LOVEGIGGLE disclosed her true feelings"). In the standard associative condition, henceforth referred to as the Word-Pair condition, an elaborate association was made between the two words by presenting them within a meaningful context, but not as part of a unified concept ("Because she was in LOVE with the boy, she would GIGGLE nervously when they met"). Memory in both conditions was tested using a cued-recall task in which participants had to complete the word pair when presented only with the first word and the first letter of the second word. The first letter of the second word was presented to aid memory performance and to reduce the likelihood of retrieving a synonym or a semantically related word instead of the correct word (e.g., "LAUGH" instead of "GIGGLE"). Providing only the first letter of the word leaves an enormous number of possible completions (all words beginning with a specific letter). Thus, this task is effectively equivalent to standard paired-associates recall tasks. We hypothesized that unitization would support memory for pairs of items even when probed using a recall test. We thus predicted that, compared to High-Performers, Low-Performers would be impaired in the Word-Pair condition, but not in the Compound condition.

2 | MATERIAL AND METHODS

2.1 | Participants

Seventy-one older adults aged 60–80 with no known neurological disorders or damage were recruited from the participant pool of the Rotman Research Institute at Baycrest Hospital. Two participants were excluded due to technical malfunctions (results in the Compound condition were not recorded). All participants provided written informed consent in accordance to the Research Ethics Board of Baycrest Hospital and were reimbursed for their participation. Demographics and neuropsychological measures of the 69 participants (mean age 71.64; 50 women) whose results were analyzed are presented in Table 1.

2.2 | Stimuli and study design

A total of 48 word pairs were generated, which do not form an existing English compound word (e.g., "love" and "giggle"). Each word pair was then entered into a Google search as a phrase (e.g., "love giggle"). The likelihood of encountering those particular two words together in everyday life was indicated by the number of search results for each pair. The mean likelihood across the 48 word pairs was 129,523 search results per pair. Note that the absolute values of the frequencies are not easily interpretable. Put simply, it is difficult to judge whether a certain number (e.g., 100,000) is high or low. Thus, these values were treated relative to one another—as compared to lower values, higher values entail that the two words are more related to one another, as they appear together in more cases.

Two similar sentences were generated for each of these word pairs, where the word pairs either formed a compound word that does not currently exist in the English language (Compound condition, e.g., "She tried to hide her affection to the boy, but her LOVEGIGGLE disclosed her true feelings"), or were used as two separate words in the sentence (Word-Pair condition, e.g., "Because she was in LOVE with the boy, she would GIGGLE nervously when they met"). This design ensured similar

TABLE 1 Demographics and neuropsychological measures

	Age	Education # years	MoCA	MoCA delayed recall	Shipley	WTAR
Mean	71.64	16.21	28.19	3.884	36.83	45.20
SEM	0.6347	0.3763	0.2148	0.1362	0.2853	0.4234
SD	5.272	3.103	1.785	1.132	2.370	3.517

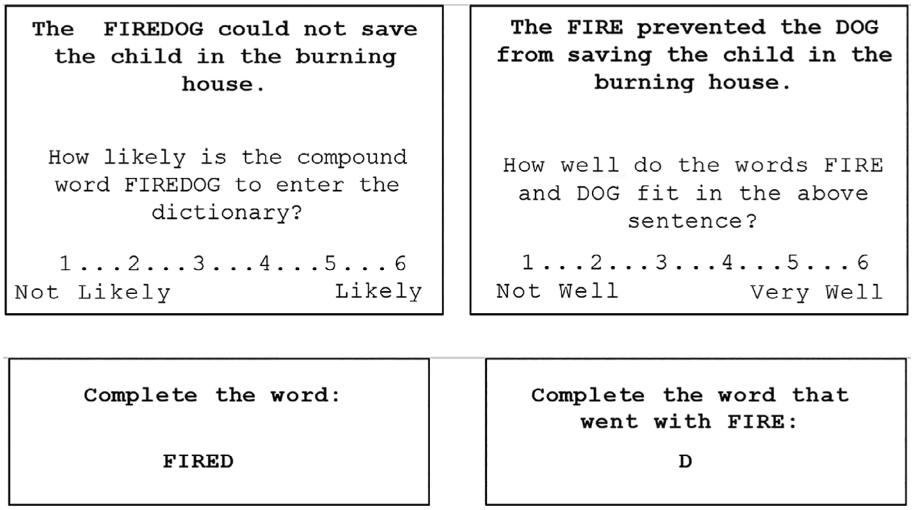

FIGURE 1 Illustration of the procedure. Top panel: Example of a study trial for the compound condition (left) and the word-pair condition (right). Bottom panel: Example of a test trial for the compound condition (left) and the word-pair condition (right)

study stimuli and recall cues in both the Compound and the Word-Pair conditions, but with different instructions to the participant. All sentences, for both Compound and Word-Pair conditions, are presented in the Supporting Information. Any additional materials and data are available from the corresponding author upon reasonable request.

The word pairs were then divided into two lists of 24. Within each list, the word pairs were divided into two equal parts that were randomly assigned to the Compound and Word-Pair conditions, and vice versa, to form a total of four test versions. Each participant was randomly assigned one of the versions. The set of 24 word pairs in versions 1 and 2 was different from the set of word pairs in versions 3 and 4. The 12 word pairs that were assigned to the Compound condition in version 1 (or 3) were assigned to the Word-Pair condition in version 2 (or 4). Likewise, the 12 word pairs that were assigned to the Word-Pair condition in version 1 (or 3) were assigned to the Compound condition in version 2 (or 4). The average number of words per sentence did not differ between Compound and Word-Pair conditions (mean number of words in Compound condition = 13.23, mean number of words in SENTENCE condition = 13.1; all p's > .3). The mean frequency of word pairs was also comparable between the two conditions and between the versions (all p's > .67). All participants completed 12 Compound trials and 12 Word-Pair trials, presented in a counterbalanced blocked design across the four versions. In two of the versions, the Compound condition preceded the Word-Pair condition and the order was reversed in the other two.

2.3 | Procedure

Testing occurred at Baycrest Hospital over a period of 1.5 hr. The experiment was programmed using E-Prime 2.0 software (Psychology Software Tools, Pittsburgh). Both Compound and Word-Pair conditions included study and test phases. During the study phase, sentences were presented twice in random order and participants were required to make a subjective judgment about the word pair used in each sentence. For the Compound condition, participants were instructed to decide how likely the compound word was to become a real English word. For the Word-Pair condition, participants were asked how well the two words fit into the sentence. A 1–6 Likert scale was used in both study phases. Participants were informed that a quiz (namely, the test phase) would follow the study phase. The sentences remained on the screen until participants made a response. In the test phase for both conditions, participants were given the first word of each word pair (the cue word) along with the first letter of the second word and were asked to complete it. In the Compound condition, participants were instructed to complete the compound word they were presented at study. In the Word-Pair condition, they were instructed to "complete the word that went with" the first word of the pair (Figure 1). After each response, participants rated their confidence from 1 to 3, with an additional response option of 0 to indicate not remembering having seen the first word at all. Participants were also asked to rate their "re-experiencing" of the compound word or word pair using a 1–6 Likert scale. All stages of the test phase were self-paced. The instructions used to describe "re-experiencing" were derived from those typically used in R/K paradigms (Gardiner & Java, 1990).

In between the Compound and Word-Pair condition, participants completed a process-dissociation procedure (PDP) to assess the contributions of recollection and familiarity to memory performance (Jacoby, 1991). Recollection is indexed as the ability to reject an item on the basis of source information, and familiarity is indexed as the probability of correctly recognizing an item given that it was not recollected. The task included four parts. In the first two parts, participants studied lists of line drawings under two encoding tasks. The first encoding task required participants to indicate whether the drawing depicted an animate or inanimate object. In the second encoding task, participants determined whether the item would fit in a shoebox. In the third part of the PDP (the "inclusion" condition), participants were given an old/new recognition test to items presented in the first two parts. Finally, the fourth part (the "exclusion" condition) probed source memory by asking participants to determine whether they had previously made a size judgment for the item on the screen. Estimates of recollection (*R*) and familiarity (*F*) were computed using the following formulae:

$$\text{(a) } R = P(\text{HIT}_{\text{inclusion}}) - P(\text{FA}_{\text{Exclusion}})$$

$$\text{(b) } F = P(\text{FA}_{\text{Exclusion}})/(1 - \text{R}).$$

Finally, participants completed the MoCA (English version 7.1), the Shipley Institute of Living Scale, and the Wechsler Test of Adult Reading (WTAR).

2.4 | Coding of recall errors

All participants' cued recall responses were collated in Microsoft Excel 2013. For each incorrect response, the type of recall error was coded into one or more of four categories: (a) response word appeared elsewhere in the experiment (e.g., it is correct response for another word pair, the response appears in that sentence or in surrounding sentences, or the participant gave the same response on another trial); (b) the cue and response word form an actual compound word (c) the response word is semantically related to the cue word, and (d) the response is almost correct (e.g., a typo or a synonym of the correct answer, or is perceptually similar to the correct word). The sum of errors in each category in the Compound and Word-Pair conditions was then calculated for each participant.

2.5 | Linguistic analysis

To investigate item effects, a linguistic analysis of the word pairs was conducted. This analysis included measures of abstractness of each word in each pair, as well as measures of semantic relatedness between each two words in a pair. Abstractness ratings were obtained from a database of 114,501 English words (Turney, Neuman, Assaf, & Cohen, 2011). This database was created by identifying 40 key words whose degree of abstractness was assessed by human annotators and subsequently propagating this information using vector semantics throughout the said vocabulary. The degree of similarity between the two words of each pair was computed using the pre-trained "Google News Negative-300" vector space model (VSM; https://code.google.com/archive/p/word2vec). This VSM was trained using the word2vec algorithm (Mikolov, Sutskever, Chen, Corrado, & Dean, 2013) on a large corpus to produce 300-long real vectors, each representing a word in the English lexicon. The similarity between the two words of each pair is represented as the cosine similarity between their respective vectors in the model.

2.6 | Statistical analyses

All statistical analyses were performed using JASP software (JASP, 2018).

3 | RESULTS

Overall, participants recalled an average of 64.01% (*SEM* = 2.43) of words in the Compound condition and 55.8% (*SEM* = 2.58) of words in the Word-Pair condition. Average confidence ratings of correct recalls were 2.75 (*SEM* = 0.26) and 2.74 (*SEM* = 0.27) in the Compound and Word-Pair condition, respectively. The average re-experiencing ratings were 4.69 (*SEM* = 0.13) and 4.61 (*SEM* = 0.14) in the Compound and Word-Pair condition, respectively. Neither confidence ratings nor re-experiencing ratings differed between conditions (*t*s < 0.56, *p*s > .58; for confidence ratings: BF_{01} = 7.15, for re-experiencing: BF_{01} = 6.43; both providing moderate evidence for the null hypothesis). With regard to ratings during study, participants gave higher ratings in the Word-Pair condition in which they were asked how well the two words fit into the sentence, than in the Compound condition, in which they judged how likely the compound word was to become a real English word (Mean Word-Pair ratings = 4.55; Mean Compound ratings = 3.01; t_{68} = 8.75, p < .001; Cohen's d = 1.05). We also examined whether the two conditions differed with regard to variability in study ratings. To this end, we calculated the standard deviation of the ratings for each participant in each condition. The means of the standard deviations did not differ between the two conditions (mean Word-Pair = 1.48; mean Compound = 1.45; t_{68} = 0.39, p = .695; Cohen's d = 0.047). The lack of difference was further confirmed with a Bayesian analysis which revealed moderate evidence for the null hypothesis (BF_{01} = 7.02).

Table 2 presents the matrix of correlations between all measures presented in Table 1 and performance in the Compound and Word-Pair conditions. Notably, both MoCA and MoCA delayed-recall scores show significant positive correlations with performance in the Word-Pair condition (MoCA: r = .362, p = .002; MoCA delayed recall: r = .265, p = .028). In contrast, performance in the Compound condition does not correlate significantly with either MoCA or MoCA delayed recall (BF_{01} = 4.496 and BF_{01} = 4.133, respectively). Thus, subtle cognitive and mnemonic impairments, as indexed by the MoCA and MoCA delayed-recall scores, respectively, are associated with performance in the standard associative memory test (the Word-Pair condition), but not with performance in the nonrelational associative memory test (the Compound condition). Age correlated significantly only with performance in the Word-Pair condition, in line with the age-related associative deficit hypothesis. Importantly, however, age did not correlate with MoCA scores nor with MoCA delayed-recall scores, with moderate evidence for the null hypothesis (BF_{01} = 4.07 and BF_{01} = 3.25, respectively). Thus, in the current sample, age and MoCA scores are independent of one

TABLE 2 Matrix of correlations between mnemonic performance in the compound and word-pair condition and all demographic and neuropsychological measures (all values are Pearson's *r*)

	Compound	Word pair	Age	Education # years	MoCA	MoCA delayed recall	Shipley
Compound	–						
Word pair	0.562***	–					
Age	−0.172	−0.295*	–				
Education # years	0.143	0.036	0.002	–			
MoCA	0.109	0.362**	−0.12	−0.039	–		
MoCA delayed recall	0.12	0.265*	−0.15	0.027	–	–	
Shipley	0.18	0.201	0.069	0.051	0.126	0.14	–
WTAR	0.16	0.246*	−0.04	0.031	0.078	0.047	0.549***

**p* < .05; ***p* < .01; ****p* < .001.

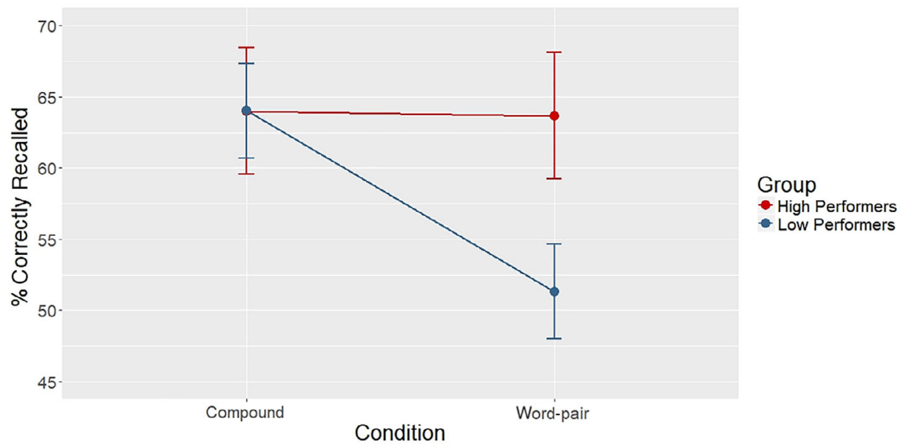

FIGURE 2 Performance in the compound and word-pair conditions for each group. Error bars represent 95% confidence intervals around the mean. A significant condition × group interaction was found ($F_{1,67} = 5.94$, $p = .017$, $\eta^2_p = 0.083$) [Color figure can be viewed at wileyonlinelibrary.com]

another. Hence, the correlations between Word-Pair performance and MoCA scores cannot be accounted for by age.

3.1 | Grouping of participants according to memory performance

As elaborated earlier, to provide a subtle measure of memory impairment, participants were divided into two groups according to their performance in the delayed-recall component of the MoCA test. Participants with a perfect delayed-recall score of 5 were included in the High-Performers Group ($n = 25$) and those with scores ≤4 ($n = 44$) were included in the Low-Performers group. The groups did not differ statistically with regard to age ($t_{67} = 1.53$; $p = .13$; $BF_{01} = 1.46$), education levels, nor the other neuropsychological measures (Shipley, WTAR; *ts* < 0.56, *ps* > 0.58, BF_{01}'s > 3). In addition, the breakdown of participants across the four versions of the Experiment did not differ between the two groups ($\chi^2 = 2.39$, $p = .5$). The Low-Performers group included six participants who failed the MoCA test (score < 26) and are thus at risk of mild cognitive impairment (MCI; Gauthier et al., 2006; Nasreddine et al., 2005; Newsome et al., 2013). For most purposes, these participants are included in the Low-Performers group. However, where relevant, this group is defined separately as "MCI-Risk."

3.2 | Compound versus word-pair recall across groups

Our main hypothesis was that recall of compound words would be relatively spared among Low-Performers (as compared to High-Performers), whereas paired-associates recall, which relies strongly on relational processing, would be relatively impaired. To test this hypothesis, the mean proportion of correct responses in each of the two conditions were submitted to a mixed 2X2 analysis of variance (ANOVA) with group (High-Performers, Low-Performers) as a between-subject factor and condition (Compound, Word-Pair) as a within-subjects factor. In addition, age was included as a covariate. Results, presented in Figure 2, reveal a significant interaction ($F_{1,67} = 5.94$, $p = .017$, $\eta^2_p = 0.083$): whereas the two groups significantly differed in their performance in the Word-Pair condition (Mean accuracy High-Performers = 63.67%, Mean accuracy Low-Performers = 51.33%), no differences were detected in the Compound condition (Mean accuracy High-Performers = 64%, Mean accuracy Low-Performers = 64.02%). A Bayesian independent sample *t* test comparing the mean proportion of correct responses in the Compound condition between the two groups further supported this result, revealing moderate evidence for the null hypothesis ($B_{01} = 3.9$). Importantly, the interaction between age and condition was not significant ($F_{1,67} = 0.63$, $p = .43$, $\eta^2_p = 0.009$), further confirming that the

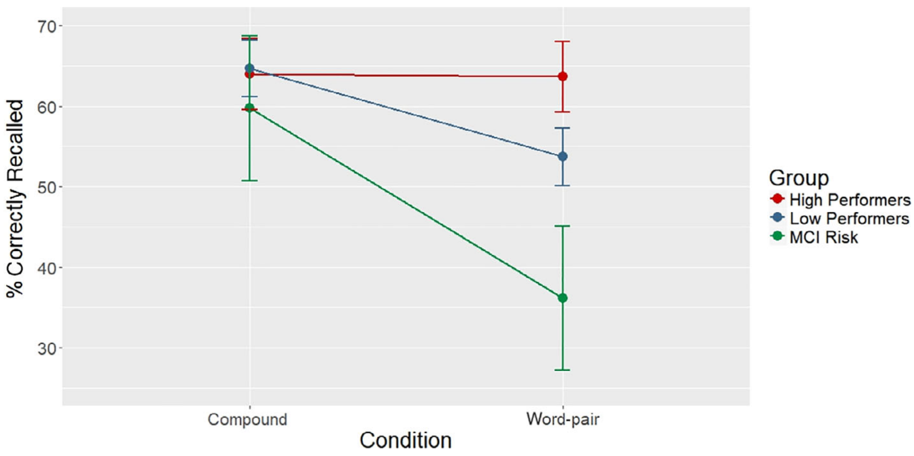

FIGURE 3 Performance in the compound and word-pair conditions for each group. Error bars represent 95% confidence intervals around the mean. A significant condition × group interaction was found ($F_{2,66}$ = 4.21, p = .019, η^2_p = 0.115) [Color figure can be viewed at wileyonlinelibrary.com]

TABLE 3 Performance (% correctly recalled) in each of the conditions, broken down by group

	Compound			Word pair		
	High-performers	Low-performers	MCI risk	High-performers	Low-performers	MCI risk
N	25	44	6	25	44	6
Mean	64.00	64.69	59.72	63.67	53.73	36.11
SEM	3.591	3.435	10.41	4.300	3.059	10.02

differences between performance in the two conditions are not accounted for by age. Our finding that High-Performers' performance on the two conditions was similar (with moderate evidence for the null hypothesis; BF_{01} = 4.72) is in line with previous research (Ahmad et al., 2015; Delhaye & Bastin, 2018; Zheng et al., 2015; Zheng et al., 2016).

We repeated this ANOVA with re-experience ratings of the two conditions as the dependent variable. None of the main effects nor the interactions were significant (all p's > .24). Further confirming this result, a Bayesian equivalent revealed that the best model was the null one and the worst that which included all factors and their interaction (BF_{01} = 151.78).

A parallel analysis in which the Low-Performers group was broken down into those who failed the MoCA test ("MCI-Risk") versus those who passed the test (Low-Performers) revealed similar results to the above analysis (see Figure 3). Performance in the Word-Pair condition showed a graded pattern: best for the High-Performers group, worse for the Low-Performers, and worst for the MCI-Risk group. In contrast, no differences were found between the three groups in the Compound condition. The statistical significance of this pattern was confirmed by a 3X2 mixed ANOVA with group (High-Performers, Low-Performers, and MCI-Risk) as a between-subject factor and condition (Compound, Word-Pair) as a within-subject factor and age as a covariate ($F_{2,66}$ = 4.21, p = .019, η^2_p = 0.115). A Bayesian ANOVA with group as the independent variable and compound performance as the dependent variable revealed moderate evidence for the null hypothesis (BF_{01} = 5.98), confirming that the groups did not differ with regard to their performance on the Compound condition (see Table 3). As in the analysis which split the participants into two groups, here too the interaction between age and condition was not significant ($F_{1,65}$ = 0.596, p = .44, η^2_p = 0.009).

3.3 | Analysis of incorrect responses

The aim of this analysis was to examine whether the pattern of incorrect responses differs between the Compound and Word-Pair conditions. Based on the coding of incorrect responses (see Methods), we classified all incorrect responses into two categories. The first, intra-item errors, included words that were related to one of the words in the pair—either the cue or the target (e.g., a word that forms an actual compound word with the cue or is semantically related to it, a word that is related to the target, either semantically or perceptually similar, a synonym of the target or a typo of the target). These errors are failures in retrieving the exact item and thus reflect item-memory errors (Jäger, Mecklinger, & Kipp, 2006). The second, intra-experiment errors, included words that appeared elsewhere in the experiment (e.g., correct response for another word pair, words appearing in the sentence or in surrounding sentences, responses given on another trial). Importantly, an error could be classified into both categories (e.g., a synonym of the target that also appeared elsewhere in the experiment). The mean number of errors in the Compound condition was 1.17 (*SEM* = 0.18) for intra-experiment errors and 1.04 (*SEM* = 0.12) for intra-item errors. The mean number of errors in the Word-Pair condition was 1.42 (*SEM* = 0.16) for intra-experiment errors and 0.58 (*SEM* = 0.09) for intra-item errors. For each participant, the proportion of errors in each condition (intra-experiment and intra-item) out of the total number of errors was calculated. The proportions of error types in each condition do

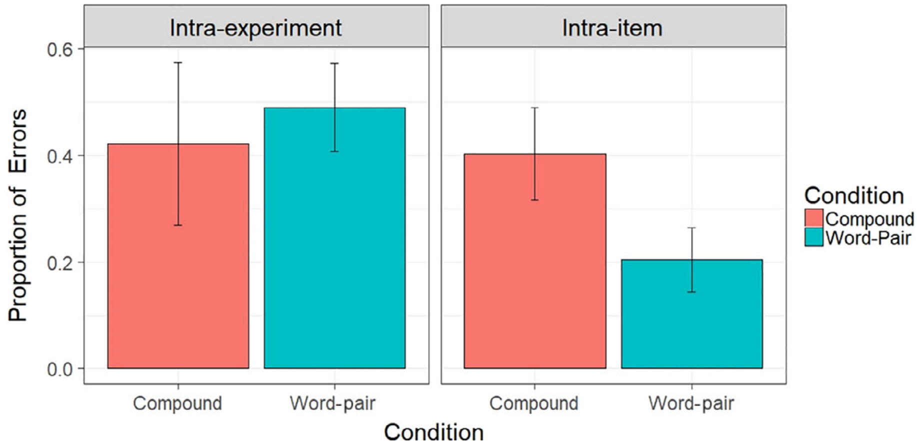

FIGURE 4 Distribution of error types in the compound and word-pair conditions. Error bars represent 95% confidence intervals around the mean. A significant difference between conditions was found with regard to the proportion of intra-item errors (t_{56} = 3.56, p < .001, Cohen's d = 0.47) [Color figure can be viewed at wileyonlinelibrary.com]

TABLE 4 Matrix of correlations between mnemonic performance in the compound and word-pair conditions and PDP estimates

	Compound	Word pair	Recollection estimate	Familiarity estimate
Compound				
Pearson's r	–			
Bf_{01}	–			
Word pair				
Pearson's r	0.562	–		
Bf_{01}	2.858e – 5	–		
Recollection estimate				
Pearson's r	0.109	0.086	–	
Bf_{01}	4.497	5.216	–	
Familiarity estimate				
Pearson's r	–0.075	–0.189	–0.166	–
Bf_{01}	5.53	2.048	2.678	–

not add up to 100% for two reasons. First, an error could fit into both categories. Second, an error could fit into neither of the two categories. Results, presented in Figure 4, revealed that the type of error was distributed differently in each of the two conditions. The mean proportions of intra-experiment and intra-item errors between the two conditions were compared with paired-sample t tests and their Bayesian equivalents. For intra-item errors, a significant difference was found between the two conditions, with a relatively larger proportion in the Compound condition (t_{56} = 3.56, p < .001, Cohen's d = 0.47). In contrast, for intra-experiment errors, the difference between conditions was not significant (BF_{01} = 6.21). Thus, intra-item errors are relatively more likely in the Compound condition.

This pattern held for both groups. For the Low-Performers, intra-item errors consisted of 33% of the mistakes in the Compound condition, and 13% in the Word-Pair condition (t_{43} = 3.48, p = .001, Cohen's d = 0.52). For the High-Performers, the same pattern was observed on a descriptive level, with intra-item errors consisting of 45% of the mistakes in the Compound condition, and 26% in the Word-Pair condition. This effect approached significance (t_{24} = 1.97, p = .06, Cohen's d = 0.39). No differences were found between the two conditions with regard to intra-experiment errors (for Low-Performers: BF_{01} = 5.99, for High-Performers: BF_{01} = 3.53).

3.4 | Correlations with R/F estimates and with measures of language

Recognition memory for unitized items, such as compound words, has been shown to rely on familiarity (Haskins et al., 2008; Parks & Yonelinas, 2015). If a similar familiarity-based mechanism also supports recall of compound words, a possible hypothesis is that performance in the Compound condition would be correlated with a measure of familiarity in recognition. To test this hypothesis, we examined the correlation between performance in the Compound condition and the familiarity estimates obtained in the PDP (Table 4). No correlation was found between the two measures (Pearson's r = –.075, p > .5; BF_{01} = 5.53). In addition, no correlation was found between performance in the Word-Pair condition and the R estimates obtained from the PDP (Pearson's r = .086, p = .48; BF_{01} = 5.22). To test whether performance in the Compound condition relies on language processes, we examined its correlation with three measures of language: the WTAR, the Shipley, and the Verbal Fluency component of the MoCA test. None of these correlations were significant (Pearson's *r*s < 0.18, *p*'s > .13; BF_{01}'s > 2.28).

3.5 | Item effects

To examine possible item effects, we analyzed two linguistic measures: (a) level of abstractness of each word in each pair and (b) semantic relatedness of the words in each pair (see Methods for further details). For each word pair in each condition, we summed the number of correct responses across all participants and examined its correlation with (a) the abstractness of the cue word, (b) the abstractness of the target word, and (3) the semantic relatedness of the two words in each pair. None of the correlations was significant (−0.15 < Pearson's *r*s < 0.21, *p*s > 0.16; BF_{01}'s > 2.11). Thus, the probability of correctly recalling an item was not related to any linguistic measure examined.

4 | DISCUSSION

The current study examined whether the pronounced deficit in associative information recall among aging individuals with subtle hippocampus-mediated memory impairments can be mitigated by utilizing mnemonic processes that decrease reliance on relational binding. Mnemonic performance of older adults with subtle memory impairments (Low-Performers) was compared with that of older adults with spared memory capacity (High-Performers). Memory in the Word-Pair condition—a standard associative information recall task, which heavily taxes relational processing—was significantly worse among Low-Performers than among High-Performers. The difference between the groups was even more pronounced when the division into groups included a small, but distinguishable, group of individuals who failed the MoCA test, and are at risk for MCI. These results are in line with the well-established disproportional associative memory deficits (Naveh-Benjamin, 2000; Naveh-Benjamin et al., 2003; Old & Naveh-Benjamin, 2008) and with the notion that memory impairments in aging are manifested primarily in relational-memory deficits (Burke & Light, 1981; Dennis et al., 2008; Giovanello & Schacter, 2012; Lyle, Bloise, & Johnson, 2006; Ryan, Leung, Turk-Browne, & Hasher, 2007; Ryan, Moses, & Villate, 2009).

In stark contrast to the group differences in traditional associative recall, performance in the Compound condition—in which the two items of the pair are unitized into a single concept—did not differ among groups, even when the MCI-risk group was differentiated from the Low-Performers. This result is in line with the notion that learning of novel associations may be supported by nonrelational processes, namely via mnemonic processing of single items, which is relatively spared among aging individuals with subtle memory impairments.

As indicated earlier, forming, retaining and recalling associations is a ubiquitous memory process, which has many real-world instantiations. To give but one example, trying to recall where we left our keys requires recalling the target (the keys' location—e.g., near the bed) given the cue (keys). An exciting avenue for future research is testing whether unitization strategies, such as those used in the current study, can be effective in such situations (e.g., unitizing between "keys" and "bed" by encoding them as the compound word KEYBED). This research could thus have important implications in treatment of age-related memory decline.

In line with the associative memory deficit account (Naveh-Benjamin, 2000), performance in the relational, Word-Pair, condition declined with age. Importantly, however, age did not account for the differences in associative memory performance between the High- and Low-Performers groups. This conclusion is supported by (a) the lack of correlation between age and MoCA delayed-recall scores; (b) the findings that the group differences between performance in the two conditions held even with age added as a covariate; and (c) the findings that there was no interaction between Condition and age (as a covariate).

Crucially, we show, for the first time, that nonrelational processing can support retrieval of novel associations not only in recognition (as has been previously shown; Ahmad et al., 2015; Delhaye & Bastin, 2018; Diana et al., 2008; Haskins et al., 2008; Opitz & Cornell, 2006; Parks & Yonelinas, 2015; Quamme et al., 2007; Zheng et al., 2016), but also in recall—a task which has long been assumed to rely predominantly on relational processing (Guderian et al., 2011; Hirst et al., 1988; Humphreys et al., 2010; Yonelinas, 2002). The difference in performance patterns between the Compound and Word-Pair conditions is all the more striking given that the retrieval cues in both tasks were identical, and that the encoding conditions were highly similar (see Figure 1). These differences were not driven by item effects, as revealed by our linguistic analyses. Nor were they driven by differences in memory-strength, as revealed by the comparable confidence and re-experiencing ratings in the two conditions. The finding that re-experiencing ratings are comparable across the two conditions is in line with previous work (Parks & Yonelinas, 2015). Thus, even though unitization promotes familiarity, it does not come at the expense of recollection. Retrieval of unitized items might still evoke recollection of details associated with the unitized item, rather than recollection of details regarding the association between the items. Last, analyses of the study ratings revealed that ratings were actually higher in the Word-Pair condition indicating that participants regarded the associations between the two words stronger in the Word-Pair condition than in the Compound condition. No differences were found between the variability in study ratings between the two conditions, arguing against possible differences in deployment of attention.

The idea that different underlying processes support recall in the Compound and Word-Pair conditions is further supported by the patterns of errors in the two conditions. Compared to the Word-Pair condition, errors in the Compound condition more likely consisted of failures to retrieve the exact item (and instead retrieval of a synonym or a semantically related item). Thus, in the Compound condition, relatively more responses were indicative of item-memory errors (Jäger et al., 2006). In both conditions, the same proportion of errors was cases in which *a* correct, but not *the* correct, item was retrieved (e.g., a word from another pair or a word that appeared in the sentence). The different pattern of errors between the two conditions was observed for both groups, indicating that across the two groups similar mechanisms account for mnemonic performance in each of the conditions.

What drives recall in the Compound condition? One possibility is that the retrieval process or processes underlying recall in the Compound condition might be akin to those underlying stem or fragment-completion recall (Graf & Schacter, 1985; Graf, Squire, & Mandler, 1984; Greene, 1986). These may include implicit or automatic associative memory processes that drive retrieval of the compound word (Graf & Schacter, 1985; Graf & Schacter, 1989). In line with this notion, automatic, habit-memory may support fragment-completion recall of the target in an associative memory task in amnesics (e.g., study: Knee–Bend, test: Knee–B-n-; Hay, Moscovitch, & Levine, 2002). In that study, the contribution of habit-memory was separated from that of recollection using a variant of the PDP task for paired-associates recall (Hay & Jacoby, 1996). Importantly, in stem- and fragment-completion recall, the stem or fragment typically include 2–3 letters, thus restricting the number of possible completions to a small number of words (e.g., 10; Graf & Schacter, 1989). In contrast, only the first letter was provided in the current task, thus the potential number of possible completions is extremely large.[1] If indeed the Compound condition relies on similar processes to those underlying stem-completion, the stem essentially includes not only the first letter of the target word (i.e., D___) but also the cue-word (i.e., FIRED___). This further confirms that the two words composing the compound were unitized into a new word. Moreover, the instructions were the same in both tasks as compared to many implicit and explicit tasks, in which in the implicit conditions participants typically are asked to complete the fragment with the first word that comes to mind or to guess, whereas in the explicit task, they are asked to provide the word they had studied.

An additional candidate process that may drive performance in the Compound condition is Fast Mapping. Fast Mapping refers to rapid acquisition of information via its integration into existing cortical, semantic networks. This process is thought to support young children's remarkable learning of a new vocabulary (Carey & Bartlett, 1978; Coutanche & Thompson-Schill, 2015). Evidence from recent years has shown that Fast Mapping can also support one-shot learning of novel associations among older adults and even amnesics, presumably via incorporation of the new association into a cortical network (Coutanche & Thompson-Schill, 2015; Merhav, Karni, & Gilboa, 2014; Sharon, Moscovitch, & Gilboa, 2011). The current task is similar to Fast Mapping paradigms in that it, too, involves rapidly integrating new concepts (namely, the compound words) into one's vocabulary. Conceivably, acquisition of new associations in the Compound condition relies on Fast Mapping in a way that is somewhat similar to how children learn new words. Note, however, that the current task differs from the Fast Mapping procedure in two important aspects. Learning via Fast Mapping is incidental and is inferred by exclusion (Merhav et al., 2014). The current task did not involve exclusion, nor was learning incidental; participants were given details regarding the subsequent memory test prior to study. Additionally, performance in the Compound condition was not associated with any of the neuropsychological measures of language performance we examined. Therefore, the possible link between Compound recall and Fast Mapping refers mainly to the idea that rapid integration of knowledge into a semantic network plays a pivotal role in memory for novel compounds.

According to dual-process models of memory, associative recognition of unitized items relies on familiarity, an idea that has been largely supported by both behavioral and neuroscientific evidence (Diana et al., 2008; Haskins et al., 2008; Parks & Yonelinas, 2015; Quamme et al., 2007). Accordingly, we hypothesized that performance in the Compound condition might be correlated with the degree to which familiarity drives item-recognition. Along similar lines, we hypothesized that performance in the Word-Pair condition might be correlated with the degree to which recollection drives item-recognition. Interestingly, however, no correlation was found between performance in the Compound condition and Familiarity estimates obtained from the PDP, or between performance in the Word-Pair condition and Recollection estimates. Two reasons may account for the lack of association between these measures. First, it is possible that somewhat different mechanisms underlie familiarity and recollection of word pairs, as compared to single items (as tested in the PDP task). Indeed, all previous studies, which reported reliance on familiarity in unitization, obtained Familiarity estimates from associative recognition tests. The second reason relates to our novel use of recall (rather than recognition) to probe memory of unitized associations. That recall of compound words relies on a nonrelational process does not necessarily entail that it relies on the same nonrelational, familiarity process that drives recognition. Recall and recognition differ fundamentally in the cues that drive retrieval: a context-cue in recall versus an item-cue in recognition (Dennis & Humphreys, 2001). Indeed, it has been shown that the recollection processes driving recall and recognition can be dissociated (Sadeh et al., 2012; Sadeh, Maril, & Goshen-Gottstein, 2012). Likewise, the nonrelational (familiarity-like) process driving recognition and possibly recall may differ between the two tests.

Unitization strategies such as those used in the current study may enhance performance in additional tasks, such as free recall. For instance, consider a standard free recall task in which participants are instructed to treat each pair of successively presented words during study as a compound. Thus, each pair of words will be unitized into a single item. Based on the current results, we expect that recall of one word will trigger recall of the adjacent word, and that this recall will be driven by nonrelational processing. Importantly, the tendency to successively recall two items from adjacent serial positions has been well documented. Referred to as the Temporal Contiguity Effect (Healey, 2018; Kahana, 1996), this tendency is assumed to reflect the workings of temporal context (Polyn, Norman, & Kahana, 2009). Thus, recall of an item triggers recall of an adjacent item because the two items share a similar temporal context. The Temporal Contiguity Effect is reduced in aging (Golomb, Peelle, Addis, Kahana, & Wingfield, 2008), a finding attributed to decline in relational binding between the item and its context. Critically, unitization between item pairs in a free recall task, as suggested here, is expected to increase the Temporal Contiguity effect in aging. However, this finding is expected to be due to an increase in reliance on nonrelational processing, rather than due to the workings of temporal context.

Last, we turn to the results of the six participants who failed the MoCA test. Notably, the MoCA scores of these participants are below the suggested cutoff of neurotypical performance, thus suggesting that these individuals are at risk for MCI or dementia (Nasreddine et al., 2005; Newsome et al., 2013). While recall capacity in such populations is markedly impaired (Pillon, Deweer, Agid, & Dubois, 1993; Welsh, Butters, Hughes, Mohs, & Heyman, 1991), the current results suggest that this impairment can be substantially mitigated (and even eliminated) when relying on nonrelational recall, as operationalized here in the Compound condition. Our results thus provide preliminary evidence suggesting that capitalizing on non-relational processes is a promising direction in alleviating recall impairments of individuals suffering from impairments due to degenerative disease or even brain injury.

5 | CONCLUSIONS

The current study reveals substantial individual differences among older adults in their ability to form and retain unitized and nonunitized associations in memory. Performance of aging adults with subtle memory impairments is consistent with that characterizing deterioration of episodic memory mediated by the hippocampus. When performance can only be driven by relational binding, these individuals show marked deficits in recall of paired-associates, as compared to successfully aging older adults. In contrast, when recall of paired-associates can be driven by nonrelational processes, via unitization, the deficit is no longer evident. Thus, the two groups of aging individuals perform comparably when unitizing the items comprising the pair into a single concept. Our study provides the first demonstration of unitization effects in recall, thereby extending recent evidence suggesting that the contribution of nonrelational processes to retrieval is not limited to recognition.

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ENDNOTE

[1] Future work is needed to determine whether similar results may be obtained without providing the first letter.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of this article.

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