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Relative contribution of associative memory and working memory to subjective organization in aging

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Abstract

Organizing information is an efficient way to improve episodic memory performance. When the information is not semantically related to each other, individuals can self-organize this information. This spontaneous subjective organization involves important working memory (WM) resources and is negatively affected by aging, potentially because it also relies on associative memory. Here, we examined whether such subjective organization involves associative processes, whether this relation is explained by WM capacity, and whether this relationship differs with age. We tested 40 young (non-students) adults and 40 older adults on two memory tasks: one allowing for subjective organization to be implemented and another accounting for associative memory processes. These participants also performed three different WM tasks to compute a WM capacity index. Whilst reporting classical age-related effects on recall, recognition and WM performance, we found that both associative memory and WM are related to subjective organization in both young and older adults. However, between these two factors, WM capacity was the main factor explaining subjective performance in both age groups, though to a greater extent in young adults. These results confirm the central role of WM in episodic memory, particularly in explaining the age-related decline of this function.

Key words: subjective organization, associative memory, working memory capacity, aging

1. Introduction

Episodic memory is the ability to remember past events and to associate them with a specific time and context (Tulving, 2002). Like other cognitive abilities, the efficiency of this form of memory decreases with aging (e.g., Nyberg, 2017). In previous decades, several hypotheses have been put forward to explain the age-related impairments of the cognitive processes involved in episodic decline (e.g., processing speed: Salthouse, 1996; executive functions: West, 1996; working memory: Hasher & Zacks, 1988). According to the *associative deficit hypothesis* (Naveh-Benjamin, 2000), the poor episodic memory performance observed in older adults can largely be explained by the difficulty they have in binding unrelated attributes of an episode within a cohesive unit (Naveh-Benjamin, 2000; Old & Naveh-Benjamin, 2008). The memory strategy of subjectively organizing unrelated items into clusters may be impacted by this associative deficit. Much like associative memory, this subjective organization strategy undergoes a marked decline with advancing age (Davis et al., 2013; Frick et al., 2023; Pinard et al., 2021; Sauzéon et al., 2006), and research indicates that both of them rely on working memory capacity (for a study of subjective organization, see Frick et al. 2023; and for studies of associative memory, see Bender & Raz, 2012; Hara & Naveh-Benjamin, 2015). In the present study, we examined whether subjective organization involves associative processes, whether this relation is explained by working memory capacity, and whether this relationship differs between young and older adults.

Associative memory is classically assessed with recognition tasks in which participants are asked to pick out word-pairs they have already seen from among word-pairs that are either new or have been rearranged (Naveh-Benjamin et al., 2000). While performance is often less impaired on recognition tasks than on free recall tasks, especially in older adults (e.g., Craik & McDowd, 1987; Pinard et al., 2021), the recognition of associations between multiple items (e.g., unrelated word-pairs) seems to be affected more in aging than the straightforward

recognition of individual items (Castel & Craik, 2003; Chalfonte & Johnson, 1996; Mitchell et al., 2000; Naveh-Benjamin, 2000; but see Rhodes et al., 2019). The specific difficulty of recognizing unrelated word-pairs reflects impairment of the associative processes that allow specific events to be linked to particular contexts (Naveh-Benjamin, 2000). Studies have shown that to create subjective context-event associations that are not already present in memory, the memory trace of each event has to be separated from its pre-existing contextual characteristics (Chalfonte & Johnson, 1996; Hockley, 1991, 1992; Johnson & Chalfonte, 1994; Johnson et al., 2000). It is these newly formed associations that older adults have greater difficulty recognizing (El Haj & Allain, 2012; Plancher et al., 2010; Spencer & Raz, 1994; Zacks et al., 2000; for a review, see Old & Naveh-Benjamin, 2008).

More specifically, this associative deficit in aging seems to be linked to the difficulty of spontaneously implementing associative verbal strategies during encoding and/or retrieval. Indeed, it has been found that prompting both young and older adults to use verbal strategies (i.e., creating sentences with the words) reduced associative deficit, especially in older adults (Naveh-Benjamin et al., 2007). This suggests that this population does not use spontaneously such strategies, potentially because of weaker controlled processes (Bender & Raz, 2012; Hara & Naveh-Benjamin, 2015). One of these processes include holding information in working memory while performing other ongoing tasks (Baddeley, 2017; Baddeley & Hitch, 1974). We can therefore reasonably assume that working memory capacity supports binding/associative processes. For instance, to learn the association between the unrelated words *tree* and *window*, individuals can produce either the verbal sentence “I see a tree by the window” or its visual representation. In other words, working memory capacity likely supports the binding of two (or more) stimuli when individuals are trying to generate (and learn) semantic links between different items, by holding verbal/visual information while cognitive processes are applied to it (Baddeley & Hitch, 1974).

Interestingly, the binding or associative process at play in associative memory also seems to be engaged when individuals initiate particular memory strategies. For instance, when individuals are presented with unrelated words and asked to recall them across several trials, they tend to recall the same groups of unrelated words across successive trials, subjectively linking these words together in their episodic memory (Howard & Kahana, 1999; Sternberg & Tulving, 1977; Tulving, 1962). Although this subjective organization strategy is strongly affected by aging, and potentially more so than any other organizational strategies (e.g., Davis et al., 2013; Frick et al., 2023; Sauz on et al., 2006; Taconnat et al., 2020), recent evidence shows that working memory capacity underlies the subjective organization of unrelated items in both young and older adults (Frick et al., 2023). As such, it might also be that subjective organization is subtended by associative processes such as those involved in the recognition of unrelated word-pairs.

The objectives of the present study were therefore to examine whether spontaneous subjective organization involves associative processes, whether this relation is explained by working memory capacity in both young and older adults, and whether this relationship differs between the two age groups. To this end, young and older adults were tested on three different memory tasks: a free recall task allowing for the implementation of spontaneous subjective organization (i.e., no explicit instructions about the use of subjective organization were given to the participant); and two recognition tasks, one featuring single items and one featuring unrelated word-pairs to test associative memory. Note that in the free recall task, subjective organization is measured over several recall trials rather than only on one occasion, so participants could in principle engage in new organizational behaviors across the retrieval attempts. We also administered several classic and widely used cognitive tests to assess working memory capacity. Based on well-established age effects, we predicted that older adults would have lower scores on working memory tasks compared to young adults, they

would recall fewer words in the free recall task, making less use of the subjective organization strategy, and would recognize fewer single items. We also predicted that word-pair recognition would be more affected by age than the recognition of single items, reflecting the age-related associative deficit. We then explored whether subjective organization involves associative processes and to what extent working memory capacity accounts for this relation, similarly or not in young and older adults (Frick et al., 2023).

2. Methods

2.1 Participants

Participants were 40 young adults (20 women and 20 men) aged 20-40 years, and 40 older adults (23 women and 17 men) aged 60-80 years (see Table 1 for demographic data)¹. All participants were native French speakers, and were recruited from the general community by advertising, word of mouth or from leisure clubs and senior-citizen universities. To reduce any potential cohort effects, none of the young adults were enrolled in higher education institutions at the time of the data collection. They took part on a voluntary basis and provided their written informed consent. All participants were individually interviewed to exclude those who had a history of alcoholism, were undergoing treatment for neurological conditions and/or psychiatric disorders or were receiving psychoactive medication. They had normal or corrected-to-normal eyesight. The participants were tested by experimenters who were also native French speakers and all tests were given in French language.

As shown in Table 1, the two groups were matched on various potential confounding factors, including anxiety and depression, education level, and verbal/vocabulary abilities, although older adults had a slightly higher level of vocabulary. The Mini-Mental State Examination (MMSE, Folstein et al., 1975) was administered to all older adults to exclude participants with a pathological cognitive impairment. All of them scored above the standard

¹ The sample size was similar to our previous work that used similar methods (Frick et al., 2022, 2023).

cut-off of 27, suggesting that they did not have any cognitive disorders. Ethical approval for the research was obtained from the institutional review board of the Psychology Department at the University of Tours. After the experiment, participants were debriefed about the general goal of the research.

Table 1. Characteristics of participants per age-group

	Young (40)	Older (40)			
	M (SD)	M (SD)	<i>t</i> (78)	<i>p</i> value	Cohen's <i>d</i>
Age	26.7 (4.45)	67.5 (5.57)	-36.15	.001	-8.08
Years of education	13.50 (1.54)	12.47 (3.30)	1.78	.079	0.40
Mill Hill	24.8 (3.86)	26.6 (4.45)	-1.93	.057	-0.43
HADS- Anxiety	4.49 (1.95)	4.7 (2.73)	0.33	.743	0.07
HADS-Depression	4.7 (2.49)	4.9 (2.75)	-0.30	.766	-0.07

Note. Mill Hill: Mill Hill Vocabulary Scale; HADS: Hospital Anxiety and Depression Scale.

Validated versions in French language were used for all these tests.

2.2 Materials and Design

Episodic memory tests.

We administered three tests of episodic memory: a free recall test to assess subjective organization and two recognition tests a single word recognition and a rearranged word-pairs recognition. The latter test measures associative memory.

Free recall test.

The material consisted of 20 semantically unrelated words that were all four to eight letters long and included one to three syllables (similar material to Frick et al., 2023; see <https://osf.io/sbqvp/>). Each word was displayed on a computer screen for 3 seconds, with an

interstimulus interval of 2 seconds. Participants were instructed to memorize as many of these words as possible. To avoid any recency effect, participants were asked to perform an interference task, the letter comparison test (Salthouse, 1990). It consists of comparing pairs of letters (X-O) and deciding whether the two members of the pair are identical or not and ticking the 'identical' or 'different' column accordingly within 45 seconds. They were then asked to recall aloud as many words from the wordlist as possible in three trials. No instructions regarding any particular mnemonic strategies were explicitly given to the participants. Each trial was preceded by a 45-s letter comparison task. Recall was audio recorded by the experimenters. Scores on the three recall trials for each participant were used to compute a pairwise frequency index measuring subjective organization, called PF (Anderson & Watts, 1969; Sternberg & Tulving, 1977) according to the following formula: $PF = O(ITR) - E(ITR)$; where $O(ITR)$ corresponds to the number of item pairs recalled consecutively in two successive trials whatever the order of recall of these two items, $E(ITR)$ is the expected value of the number of intertrial repetitions and is calculated as follows:

$$E(ITR) = c(c-1) / h k$$

with c corresponds to the number of items recalled both to trial t and trial $t+1$, h corresponding to the total number of words recalled, at trial t , and k corresponding to the number of total words recalls at trial $t+1$. According to this formula, the higher the index, the better the organization. Note that two PF scores were therefore obtained based on these three recalls.

Recognition tests.

The recognition tests, single-item and rearranged word-pair recognition, were adapted from two previous seminal studies of associative memory (Bender & Raz, 2012; Naveh-Benjamin, 2000). For the encoding phase, we created 52 unrelated word-pairs (e.g.,

oven-treasure; French: four-trésor) and used them to build two different lists of 26 word-pairs (List 1 and List 2). Two additional lists were created, labelled 1b and 2b, with the same 26 words-pairs of List 1 and List 2, but the target and cue words were reversed (e.g., oven-treasure in List 1 became treasure-oven in List 1b; see Supplementary Material). Participants showed only one list (either List 1, List 1b, List 2 or List 2b) and were then tested on both a single-item and a word-pair recognition test on that list (order counter-balanced across participants).

Each word pair was displayed on a computer screen for 5 seconds, with an interstimulus interval of 2 seconds. Participants were told to memorize both the individual words and the word-pairs. They then performed the two self-paced recognition tests for items and associations. For the single-word recognition test, 16 words were presented one by one, 8 from the preceding list of 26 pairs of words and 8 new words that served as distractors, and participants had to say “Yes” (French: Oui) or “No” (French: Non), depending on whether they believed they had seen the words in the encoding phase. For word-pair recognition test, 16-word-pairs were presented with 8 pairs that were seen previously and 8 recombined word-pairs (words previously seen but in the different word-pairs). Participants only said “Yes” to previously seen word-pairs. None of the words seen in the encoding phase appeared in more than one test.

Each test was preceded by a practice phase in which 3 word-pairs were presented, followed by 3 words for single-item recognition (2 previously seen words and 1 new word) and 3-word-pairs for the word-pair recognition (1 word-pair previously seen and 2 recombined word-pairs).

Working memory assessment

We administered three classic cognitive tasks to assess working memory

N-back test (Kirchner, 1958).

Participants performed a verbal 2-back test. The experimenter read out 30 letters of the alphabet (F, L, S, R, B, P, D, G, M, or N), at a pace of one per second. Participants were asked to say “Yes” if the letter they heard was the same as the letter they heard two items before, and “No” if it was not. The score was the number of correct responses.

Backward Digit Span (Wechsler, 2008).

The experimenter read out strings of digits (from 1 to 9) at a rate of one per second, and participants were asked to repeat them verbally in the reverse order (i.e., 1-3 → 3-1). The number of digits in each string increased by one digit each time participants gave at least one correct answer for a given string length. The minimum length was two digits, and the maximum was eight digits. The task ended when participants failed two consecutive trials for the same length. The score was the maximum number of digits the participant was able to recall correctly.

Categorization Working Memory Span test (adapted from Borella et al., 2008; see Borella et al., 2010).

This task is similar to the classic working memory tasks (see Bopp & Verhaeghen, 2005). It requires participants to process lists of words instead of sentences, thereby limiting the role of semantic processing. The material consists of eight sets of 20 word lists. Each list contains five high-to-medium frequency words of varying lengths (from 2 to 6 letters), including 0, 1 or 2 words that specifically correspond to animal nouns in various locations (e.g., house, mother, *dog*, word, night; French: maison, mère, *chien*, mot, nuit), including the final position. The word lists are read out at a rate of one word per second, and participants have to tap the table whenever they hear an animal word (processing phase). There is a between-list interval of 2 seconds. The presentation is therefore paced by the experimenter. At the end of each set, participants must recall the last word of each list (i.e., 20 words) in the

right order (maintenance phase). The total number of correctly recalled words is taken as a measure of the participant's working memory capacity.

To reduce the working memory data, we calculated a working memory composite index for each participant, which is the mean of the 3 z-scores for the working memory measures and thus represents the participant's working memory capacity.

2.3 Data availability statement

The data and analytic code are available on the Open Science Framework:

https://osf.io/u65q7/?view_only=1af09f5f25fa4eb38c48c5888ce3edb9

2.4 Data processing

Analyses were performed on R (R version 4.3.1).

To test our hypotheses on well-established age effects on memory performance, we first performed mixed ANOVAs on free recall performance as well as on PF index with age group (young, older) as between-subjects factor in both ANOVAs and trial number (1, 2, 3) or PF score (trial 1 vs. trial 2 or trial 1-2; trial 2 vs. trial 3, or trial 2-3) as a within-subject factor. A similar analysis was done on recognition performance with age group as a between-subject factor and task type (single word, word pair) as a within-subject factor. We then analyzed the effects of age group on each working memory measure and on the working memory index using a one-way ANOVA. These ANOVAs were performed using the *afex* package and the function *aov()*.

Associations between associative memory, working memory and subjective organization were examined using correlational analyses on the recognition score and PF index (means of the PF score from trial 1 to trial 2, and the PF score from trial 2 to trial 3) and the working memory index (z-score).

To investigate the respective contribution of associative memory and working memory on subjective organization, and explore how it is subjected to age-related changes, we ran a

hierarchical regression analysis including relevant predictors and interaction between them in different steps. Specifically, we first included age group only (Step 1), age group + associative memory (Step 2), age group + associative memory + working memory index (Step 3), all these main predictors + associative memory \times age group (Step 4), all these main predictors + associative memory \times age group + working memory \times age group (Step 5) (see Supplementary Material). At each step, we used the *anova()* function to compare the models and assess the statistical significance of the changes in R^2 (proportion of the variance explained) as we added a new predictor at each step. If the change was not significant, it meant that the best fitting model was identified and we stopped the addition of new predictors at this step. If the change was significant, we proceed with adding a new predictor until a new addition did not change R^2 or until we reached Step 5. Once the best fitting model identified, we examined the individual significance of each predictor of that particular model. This procedure allows to assess the contribution of each predictor once all important predictors are included in the best fitting model. We used the package *performance* to check any sign of collinearity between the predictors of the full model (Step 5), which indicated no signs of strong correlations between the predictors (all VIFs < 5.23).

Pairwise comparisons were done with the package *emmeans* (Lenth et al., 2023) with appropriate post-hoc corrections (Tukey) when needed. Plots were generated with the package *ggplot2* (Wickham, 2011).

3. Results

3.1. Age group and trial effects on free recall performance

Analyses revealed a main effect of age group, $F(1, 78) = 61.49, p < .001, \eta^2 p = .44$, indicating that older adults recalled fewer words than young adults ($M = .39$ vs. $M = .61$). There was a trial effect, $F(1.44, 112.38) = 7.77, p < .001, \eta^2 p = .09$, indicating that

performance from trial 1 to 2 significantly declined, but not from trial 2 to trial 3 ($M = .52$ vs. $M = .49$ vs. $M = .49$; $p = .009$ and $p = .987$). Results showed also a significant two-way age group \times trial interaction, $F(1.44, 112.38) = 9.36$, $p < .001$, $\eta^2 p = .11$, indicating that whereas recall performance did not change across trials for young adults ($M = .61$ vs. $M = .61$ vs. $M = .62$; $ps > .788$), performance decreased significantly between the first and second trials for older adults with no difference in recall between the second and third trials ($M = .42$ vs. $M = .38$ vs. $M = .37$; $p < .001$ and $p = .655$; see Figure 1A). Young adults recalled significantly more words than older adults in all trials, $ps < .001$.

3.2 Age group and trial effects on subjective organization

Results revealed main effects of age group, $F(1,78) = 18.52$, $p < .001$, $\eta^2 p = .19$, and trial, $F(1,78) = 58.07$, $p < .001$, $\eta^2 p = .42$, indicating that young adults used more subjective organization than older adults ($M = 2.94$ vs. $M = 1.78$) and that subjective organization was better from the trials 2-3 than from the trials 1-2 ($M = 2.73$ vs. $M = 1.99$). There was a significant interaction between the two, $F(1,78) = 10.30$, $p < .001$, $\eta^2 p = .12$, indicating that the increase in subjective organization between the 1-2 and 2-3 trials was greater in the young group ($M = 2.42$ vs. $M = 3.47$, $t = 7.66$, $p < .001$) than in the older group ($M = 1.57$ vs. $M = 1.99$, $t = 3.11$, $p = .003$; see Figure 1B). Young adults used more subjective organization than older adults in both trials, $ps < .001$.

3.3 Age group and type of task effects on recognition performance

For recognition, analyses revealed a main effect of age group, $F(1,78) = 20.21$, $p < .001$, $\eta^2 p = .21$, indicating that young adults generally recognized more items than older adults ($M = .61$ vs. $M = .49$). A significant effect of type of task was also found, $F(1,78) = 21.76$, $p < .001$, $\eta^2 p = .22$, showing a better performance in the single word condition than in the word

pair condition ($M = .61$ vs. $M = .49$). There was a significant age group \times type of task interaction, $F(1,78) = 5.62$, $p = .020$, $\eta^2p = .07$, showing that older adults recognized significantly fewer items in the word pair recognition task than in the single word recognition task ($M = .40$ vs. $M = .58$; $p < .001$), whereas there was no difference between these two tasks for young adults ($M = .64$ vs. $M = .54$; $p = .109$; see Figure 1C). Recognition performance of young and older adults did not significantly differ in the single word recognition task, $p = .097$, but young adults recognized more word-pairs than older adults in the word-pair recognition task, $p < .001$.

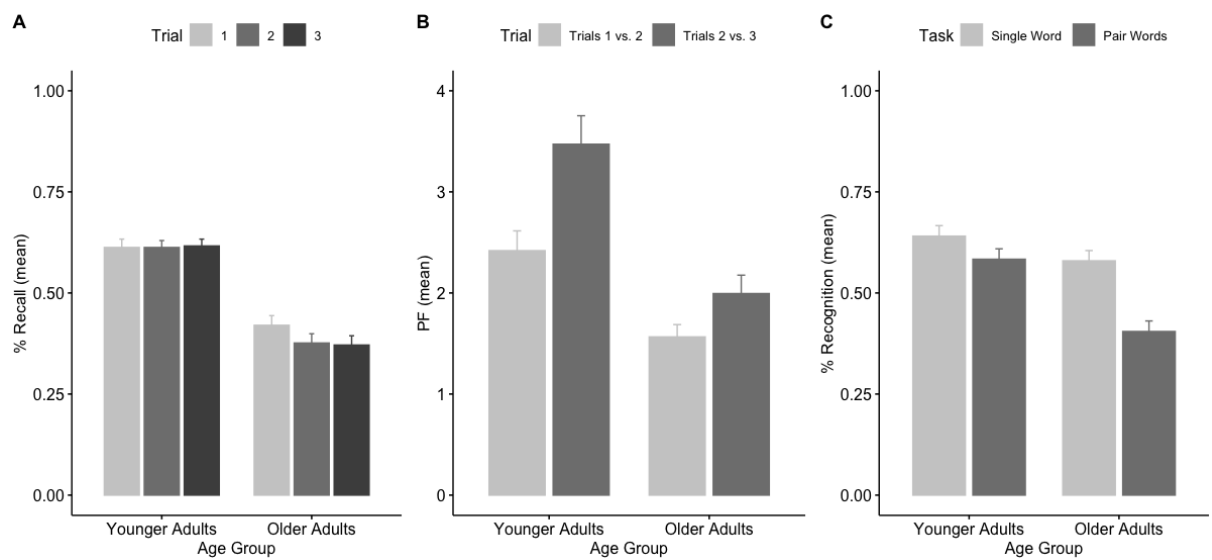


Figure 1. Percentage of recall according to age group and trial (A), mean of PF as a function of age group and trial (B) and percentage of recognition as a function of age group and task type (C). Error bars represent standard errors.

3.4 Age group effect on working memory measures

Results indicated a significant age group effect on the N-back test, $F(1, 78) = 19.97$, $p < .001$, $\eta^2 p = .20$; on the Backward Digit Span, $F(1, 78) = 33.28$, $p < .001$, $\eta^2 p = .29$, on the Categorization Working Memory Span test, $F(1, 78) = 52.15$, $p < .001$, $\eta^2 p = .40$, and on the

working memory composite index, $F(1, 78) = 47.67, p < .001, \eta^2 p = .37$. All of these effects were in line with the well-known decline in working memory with age.

3.5 Relationship between age group, associative memory, working memory and subjective organization and predictors of subjective organization between age group, associative memory, and working memory

In order to examine the relationship between associative and working memory, and between these two variables and subjective organization, correlations were calculated for each age group. For both groups the results showed significant positive correlations between associative memory and working memory (young: $r = .47, p = .002$, older: $r = .51, p < .001$) between associative memory and subjective organization (young: $r = .50, p < .001$, older: $r = .35, p = .027$) and between working memory and subjective organization (young: $r = .69, p < .001$, older: $r = .45, p = .004$).

We then examined whether associative memory and working memory were similarly or differently underlying subjective organization in younger and older adults. The hierarchical regression analysis (see Table 2) first revealed that at Step 1, age group contributed significantly to the regression model, $p < .001$, and accounted for 18% of the variation in subjective organization. Introducing associative memory (Step 2) explained an additional 14% of variation, and this change in R² was significant, $p < .001$. Adding then working memory (Step 3) further added 12% of additional explanation, which was also significant, $p < 0.001$. Importantly, adding the interaction between age group and associative memory (Step 4) added a significant 3% of variation, $p = .026$, and the interaction between age group and working memory (Step 5) further explained a significant 4% of variance, $p = .012$. Therefore, the best model was the full model (Step 5) including the main predictors and the two two-way

interactions of interest. Significant testing on this model revealed a main effect of working memory, $b = 1.35$, $t = 4.93$, $p < .001$, as well as a significant interaction between age group and working memory, $b = -0.92$, $t = -2.57$, $p = .012$. However, neither age, $b = 0.60$, $t = 0.76$, $p = .837$, associative memory, $b = 1.99$, $t = 1.89$, $p = .063$ and the interaction between these two predictors, $b = -1.09$, $t = -0.73$, $p = .468$, reached significance. These results therefore indicated that subjective organization is more predicted by working memory than associative memory, and to a greater extent in younger adults than in older adults.

Table 2. Hierarchical regression analysis on the subjective organization performance with age group, associative memory, working memory, the interaction between age group and associative memory and between age group and working memory included in the equation.

Step	Predictors	R²	ΔR²	F	p-value
1	age group	0.18	0.18	30.72	$p < .001$
2	age group + associative memory	0.32	0.14	23.62	$p < .001$
3	age group + associative memory + working memory	0.44	0.12	19.86	$p < .001$
4	age group + associative memory + working memory + age group × associative memory	0.47	0.03	4.56	$p = .026$
5	age group + associative memory + working memory + age group × associative memory + age group × working memory	0.51	0.04	6.63	$p = .012$

Discussion

The present study replicated well-established findings in the aging literature for associative memory and spontaneous subjective organization, with the rare specificity that the young adults tested were not enrolled in any university programs unlike most previous studies (Henrich et al., 2010). But of perhaps more interest, it also assessed whether subjective organization involves associative processes, whether this relation is explained by working memory capacity in both young and older adults, and whether this relationship differs between the two age groups.

First, older adults recalled fewer words than young adults. Interestingly, recall performance decreased across trials for older adults, whereas young adults performed similarly across all three trials. This result is in line with previous studies showing that young adults are able to maintain similar recall performances across trials (Frick et al., 2023; Sauz on et al., 2006; Taconnat et al., 2020). Regarding how participants spontaneously organized the words in a subjective manner, we also replicated a well-established age effect, with young adults exhibiting better organizational behavior than older adults (e.g., Davis et al., 2013; Sauz on et al., 2006), although efficient use of this strategy increased across trials in both age groups (Frick et al., 2023; Taconnat et al., 2020). Linking recall and organizational performance, it appears that younger adults increasingly used spontaneous subjective organization across trials, and this allowed them to maintain constant recall performance throughout the task. By contrast, older adults may forget words belonging to clusters across trials (decrease in recall performance) but successfully recall words that are subjectively organized in clusters (increase in subjective organization index; for similar findings regarding both recall and subjective organization; see, e.g., Taconnat et al., 2020). More research is needed to establish whether the maintenance of spontaneous subjective organization over trials in older adults is related to potential confounding task-related factors.

We also replicated findings from associative memory studies supporting the associative deficit hypothesis (Naveh-Benjamin, 2000) by showing that this type of memory is particularly impaired in older adults, especially the recognition of word-pairs as opposed to single items (for a review and meta-analysis, see Rhodes et al., 2019, but see also Green & Naveh-Benjamin, 2020). Indeed, in our sample, young adults' recognition performance did not differ between single items and word-pairs, whereas older adults' recognition performance was poorer for word-pairs than for single items.

All in all, our study replicated many previous well-established findings. However, its main contribution lies in the investigation of potential similarities in the controlled cognitive processes involved in associative memory and spontaneous subjective organization, and in examining whether they are affected by aging and processing resources (i.e., working memory capacity). The regression analyses allowed us to estimate the contribution of working memory within the relationship between associative memory and the spontaneous use of subjective organization in both young and older adults which, to our knowledge, has not yet been studied in previous studies. Results initially showed that age group was a strong contributor of the use of subjective organization. However, its unique contribution was significantly reduced once working memory and associative memory were included in the model. Associative memory alone explained a significant additional portion of the variance in subjective organization after age was accounted for, but this effect was no longer substantial when testing the significance of each individual predictor in the best fitting model. Similarly, the interaction between age group and associative memory accounted for a small but significant portion of the variance when added, yet it did not predict subjective organization after all variables were included. Conversely, working memory was a significant independent predictor of the use of subjective organization overall, but this relation was significantly stronger in younger adults than in older adults (significant working memory \times age interaction

when all factors are accounted for). Note that similar results were obtained if working memory (and its interaction with age group) was entered before associative memory (and its interaction with age group; see Supplementary Material).

These results are important because they confirm that although spontaneous subjective organization involves associative processes as we expected, this involvement is mostly underpinned by working memory processes. This is consistent with previous work highlighting that associative memory relies on individuals' working memory capacities (Bender & Raz, 2012; Hara & Naveh-Benjamin, 2015). Critically, this relation was found in both young and older adults, which could suggest that the age-related effect on working memory (Hasher & Zacks, 1988) does not cancel this relationship. But the significant interaction we found nevertheless strongly indicates that the involvement of working memory in associative and subjective organization processes are greater in young adults than in older adults. This result echoes theoretical conceptions supported by behavioral findings arguing that variations in task demands strongly influence age-related differences in the use of executive and working memory processes (see the Compensation-Related Utilization of Neural Circuits Hypothesis or CRUNCH model; Reuter-Lorenz & Park, 2014; Isingrini et al., 2015). For instance, Isingrini et al. (2015) showed that older adults mainly engage efficient executive processes during low-load tasks, whereas young adults exert these processes preferentially under higher loads of task demands. Thus, although speculative at this point, it is plausible that in the context of the relationship between associative memory and spontaneous subjective organization, young adults engage working memory processes more extensively to optimize this organization as task demands increase (i.e., in a task that mainly needs the use of this type of mnemonic organization), which could in turn explain the greater variance accounted for by working memory in this age group as compared to older adults.

Relatedly, an interesting open question for future research would be to test other organizational behaviors such as semantic organization to explore whether associative processes are also involved, and if so, whether they are similarly or differently underpinned by working memory in aging. Indeed, semantic organization has been found to be less costly than subjective organization (Frick et al., 2023), so the relation between semantic organization and associative memory should be weaker, with a potential smaller contribution of working memory compared to its contribution to subjective organization. Given that less working memory processes are needed, their contribution could also be similar between young and older adults, potentially explaining why the latter can sometimes maintain a high level of semantic organization (Frick et al., 2022).

One limitation of the present study is that a power analysis was not conducted prior to data collection. Although our sample size of 40 participants per age group aligns with previous work using similar questions and methods (e.g., Frick et al., 2022, Frick et al., 2023), recruitment constraints (i.e., younger adults were not enrolled in higher education institutions) limited the availabilities of potential participants we could include. We nevertheless conducted a post-hoc power analysis using G*Power (Faul et al., 2009) for the full hierarchical regression model (Step 5), which indicated that the overall power was high (0.99). Post-hoc analyses for individual predictors showed that the study was sufficiently powered to detect the main effect of working memory and its interaction with age (power > 0.80). However, power was lower for recognition and age-related effects (power < 0.60), suggesting that nonsignificant findings for these effects should be interpreted with caution. Future studies with larger samples are needed to more robustly examine these effects.

To conclude, we were able to replicate well established effects of aging on associative memory and spontaneous subjective organization. More importantly, the results clarified that the association between associative memory and subjective organization would be

underpinned by working memory for both young and older adults, although to a greater extent in the former than in the latter. These results confirm the key role of working memory in the functioning of episodic memory, and by extension, the decline of this function with aging.

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