The respective contribution of cognitive control and working memory to semantic and subjective organization in aging

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Declaration of interest

None.

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Author Note

The data, the analytic code and the list of words used for the memory tasks used in this article can be found on the Open Science Framework depository at https://osf.io/sbqvp/?view_only=c97a3ff072594934861bc3110d4bc531

The findings presented here have not being disseminated elsewhere.

Abstract

Organizing information is beneficial to episodic memory performance. Among several possible organizational strategies, two consist of organizing the information in semantic clusters (semantic organization) or self-organizing the information based on new associations that do not exist in semantic memory (subjective organization). Here, we investigated in a single study how these two organizational behaviors were underlined by different controlled processes and whether these relations were subjected to age-related differences. We tested 123 younger adults (n = 63) and older adults (n = 60) on two episodic memory tasks, one where the words were organizable and another where the words were not organizable, allowing for semantic and subjective organization, respectively. Additionally, participants were tested on three cognitive control tasks (Wisconsin Card Sorting Test, Stroop Test and Trail Making Test) and three working memory tasks (Backward Digit Span, Alpha Span and N-back test). Results revealed well-established age-related differences in terms of recall performance and organizational strategy implementation. More importantly, we found evidence that the different cognitive tests statistically yielded two different latent factors, a cognitive control factor and a working memory factor. Based on this dissociation, we found that only cognitive control contributed to semantic organization in all age groups whereas only working memory contributed to subjective organization, also in all age groups. These results shed new lights on our understanding of how controlled processes differently contribute to organizational behaviors in episodic memory.

Key words: semantic organization, subjective organization, cognitive control, working memory, aging

Public Significance Statement

This article shows that cognitive control and working memory are dissociable processes based on the cognitive tests used here. Importantly, it was found that these processes contribute differently to different mnemonic organization strategies. Cognitive control contributes more to the organization of words based on their semantic categories whereas working memory contributes more to the self-organization of unrelated words. These findings appear to be found similarly in younger and older adults.

Introduction

Episodic memory refers to remembering personal past events associated with their spatial and temporal contexts (i.e., what, when, where; Tulving, 2002). This specific memory system is particularly altered with aging (for reviews, see Nyberg, 2017; Oschwald et al., 2020, Rhodes et al., 2019), especially due to a decline in using adapted memory strategies (e.g., Guerrero Sastoque et al., 2019; Shing et al., 2008; Taconnat et al., 2009). Indeed, memory strategies are known to increase memory performance when they are used, through semantic processing (e.g., Craik & Lockhart, 1972; Craik & Tulving, 1975), creating mental images of verbal stimuli (e.g., Burger et al., 2017; Paivio & Csapo, 1973), and organizing information (e.g., Bousfield, 1953; Taconnat et al., 2020). As a function of the nature of the material or of the memory task, a particular strategy can be more or less efficient (for a review, see Froger et al., 2014). For a free recall task, the most difficult episodic memory test, organizing the information is particularly well-adapted to improve performance (e.g., Denney, 1974; Mulligan, 2004; Puff, 1979; Taconnat et al., 2020; Zaromb & Roediger, 2010). In this study, we investigated the effect of age on the use of two different organizational strategies, namely subjective and categorical organization, as well as their underlying cognitive processes.

Two important organizational components affecting the structure of memory retrieval have been highlighted. In free recall tasks, where no cues are provided to aid retrieval, individuals may rely on pre-existing knowledge of semantic relationships (based on semantic memory), which may be present in a list of items, and/or on newly formed contextual associations among the list of items (based on episodic memory). These two organizational strategies are generally expressed by the output order of recall. In the former case, categorical organization leads individuals to recall categorically related words in clusters, even when the items are presented in random order (Bousfield, 1953; Denney, 1974; Frick et al., 2022; Romney et al., 2016; Sauzéon et al., 2006; Taconnat et al., 2009, 2020). Contrastingly, in the latter case, episodic memory makes individuals to engage in a subjective organization of a list of unrelated items (i.e., items not constrained by pre-existing categorical or associative relations), as evidenced by the tendency to recall consecutively the same words across successive recall trials (Sauzéon et al., 2006; Sternberg & Tulving, 1977; Taconnat et al., 2020; Tulving, 1962). Note that it is also possible that individuals use subjective organization when items are categorically associated, and that they could also use a "subjective semantic" organization to learn an unrelated word-list, although these cases are not addressed here and are beyond the scope of the current paper. Critically, the use of either organizational strategy is dependent upon the materials to be learnt and the methodological procedure of the memory test. Indeed, if the items are not categorically associated, then subjective organization based on personal associations is possible, but not categorical organization. Moreover, contrary to categorical organization which needs only one trial to be assessed, subjective organization needs several trials to be examined (Sternberg & Tulving, 1977).

In aging, a decrease of organizational processes is classically observed, but subjective organization seems to be more impaired than categorical organization (hereafter termed semantic organization). Indeed, to our knowledge, all studies tackling subjective organization have reported a negative effect of age on this process (e.g., Hultsch, 1974; Kausler, 1994; Light, 1991; Sauzéon et al., 2006; Stuss et al., 1996; Taconnat et al., 2020; Witte et al., 1990). Conversely, findings have been mixed for semantic organization with some studies reporting impairments with age (Denney, 1974; Froger et al., 2009; Howard et al., 1981; Taconnat et al., 2020; West & Thorn, 2001; Zivian & Darjes, 1983), or only in very old age (Cherry et al., 2012), while others revealed no such effect (Park et al., 1989; Rankin et al., 1984; Sauzéon et al., 2006, 2016). These declines are likely due to the alteration of prefrontal cortex (PFC) functioning during aging (Raz, 2000, 2005). Indeed, this brain area is known to be critical for the implementation of organizational strategies as evidenced by neuroimaging data (Blumenfeld & Ranganath, 2006; Kirchhoff et al., 2014) as well as neuropsychological and behavioral data showing lower mnemonic organizational processes in patients with frontal lesions (Gershberg & Shimamura, 1995; Kramer et al., 2005; Rocchetta & Milner, 1993) or with lower frontal activities such as depressed patients (Taconnat et al., 2010).

The PFC underlies both cognitive control (e.g., Yuan & Raz, 2014) and working memory (e.g., Barbey et al., 2013), suggesting that these two controlled processes play a key role for the implementation of organizational strategies. Critically, age-related decline is observed in cognitive control, also termed as executive functions (e.g., Ferguson et al., 2021; Taconnat et al., 2022) as well as in working memory capacities (e.g., Fabiani et al., 2016; Hasher & Zacks, 1988; Salthouse, 1994). Age-related decline in cognitive control and in working memory could contribute to lower episodic memory performance in older adults (e.g., Angel et al, 2011; Bouazzaoui et al., 2014; Taconnat et al., 2022 for research on the relationships between executive functions and episodic memory, and for research on the relationships between working memory and episodic memory, see Bender & Raz, 2012; Hara & Naveh-Benjamin, 2015). Although cognitive control and working memory are often associated and share a common underlying executive attention component (McCabe et al., 2010; and see Guerrero et al., 2022, for a discussion on this point), they may not represent the same capacities. Indeed, while both cognitive control and working memory are goal-directed processes regulating information, only working memory comprises a storage component to attain goals (Friedman et al., 2006; Friedman & Miyake, 2017; Miyake et al., 2000; Miyake & Friedman, 2012). At the brain level, the mid-ventrolateral region of the PFC cortex has been shown to support the organization of information retrieved from posterior areas (semantic memory), whereas the mid-dorsolateral region supports the active manipulation stored in working memory (Owen et al., 1999; 2005), suggesting that distinct areas of the frontal lobes are differently implicated in cognitive control and working memory.

Importantly, recent behavioral research on individual differences has shown the three core components of cognitive control (shifting, inhibition, updating; Miyake et al., 2000) are not related to working memory capacity (Frischkorn et al., 2019; Frischkorn et al., 2022; Rey-Mermet et al., 2019; but see also Draheim et al., 2021).

Semantic organization could be especially rooted in cognitive control processes related to the retrieval of semantic knowledge (i.e., semantic categories) whereas subjective organization could be associated to the integration and storage of information entering working memory. For example, Taconnat et al. (2009) showed that a decline in cognitive control was associated with semantic organization impairments in older adults (see also Taconnat et al., 2010, for an experiment in depressive patients with low cognitive control). Note that in their study, the authors did not explore the role of working memory in semantic organization. Thus, the relations between cognitive control and semantic clustering found by Taconnat et al. (2009) does not preclude a relation between working memory and semantic clustering. In another study, Kuhlman and Touron (2016) explored the link between semantic organization and working memory. They asked participants to learn an organizable wordlist without specific instruction about a possible organization of the words (i.e., spontaneous semantic organization), or telling participants that the words belonged to a few semantic categories and that using these categories could facilitate learning and word recall (i.e., instructed semantic organization). Their results showed that only the instructed semantic organization condition was associated to working memory. It is possible that individuals engage more effort during instructed semantic organization than spontaneous semantic organization as they are aware of the best strategy to adopt in advance in order to facilitate recall. Although hypothetical, this would explain why the former type of semantic organization is associated to working memory but not the latter. However, in a recent study, Cherry et al. (2021) found that semantic organization was associated to working memory although the participants were not provided with clustering instructions. Thus, it is not clear whether spontaneous semantic organization is closely associated to working memory or not.

No study has directly explored the cognitive mechanisms underlying subjective organization. This strategy relates to subjectively forming new associations between semantically unrelated items. This ability to create new associations in episodic memory, necessary for subjective organization, could be closely linked to associative memory. Associative memory involves binding unrelated items into a coherent memory episode. According to the *Associative Deficit Hypothesis* (Chalfonte & Johnson, 1996; Naveh-Benjamin, 2000), older adults have particular difficulties in encoding or retrieving the associations among the components of memories, which would explain in part the age-related decline in episodic memory. Reduced associative memory in older adults (e.g., Bender et al., 2010; Mitchell et al., 2000; Naveh-Benjamin, 2000) could be due to a deficit in cognitive resources, such as attentional processes (Kilb & Naveh-Benjamin, 2007) or working memory (Bender & Raz, 2012; Hara & Naveh-Benjamin, 2015). Though working memory has not always been associated with episodic memory, in particular associative memory (see Bartsch et al., 2019), there are nevertheless reasons to suspect that working memory might be crucial for subjective organization as working memory contributes to associative memory.

In the present study, we investigated semantic organization and subjective organization with two free-recall memory tasks, and their relationship with cognitive control and working memory measures in younger and older adults. Therefore, our general research question was to examine whether cognitive control and working memory contribute differently to organizational behaviors in episodic memory and whether their contributions are subjected to age-related changes. The prerequisite, in order to achieve our objectives, will be to first verify that the measures of working memory and cognitive control actually measure two independent cognitive components. To answer these questions, we derived two confirmatory (1 and 2) and three exploratory (3, 4 and 5) hypotheses, which are described below. We first sought to replicate well-established findings with younger adults showing better recall, semantic and subjective organization (e.g., Sauzéon et al., 2006; Taconnat et al., 2020; Hypothesis 1) as well as higher cognitive control and working memory performance than older adults (e.g., Braver, 2008; Rhodes et al., 2019 ; Hypothesis 2). Then, we tested the participants with six cognitive tests that are theoretically designed to tap either cognitive control or working memory. This allowed us to statistically test that cognitive control and working memory are two distinct controlled processes (Hypothesis 3). Based on this dissociation, we predicted that semantic organization would be mainly underlined by cognitive control, in accord with previous research (e.g., Taconnat et al., 2009), whereas subjective organization would be mostly sustained by working memory consistent with studies that showed that associative memory would be linked to working memory (e.g., Bender & Raz, 2012; Hara & Naveh-Benjamin, 2015; Hypothesis 4). This result would also be in line with the findings of neuroimaging studies which reported that working memory could contribute to episodic memory through its role in managing the relationships between items. This would promote the strengthening of inter-item association, leading on to improving episodic memory, in accord with the idea that associative memory is a major component of episodic memory functioning (e.g., Chalfonte & Johson, 1996; Naveh-Benjamin, 2000). Finally, we predicted the contributions of cognitive control and working memory to these organizational processes could be subjected to age-related differences (Hypothesis 5).

Method

Transparency and Openness

The data, the analytic code (written in R) and the list of words used for the memory tasks can be found on the Open Science Framework depository at https://osf.io/sbqvp/?view_only=c97a3ff072594934861bc3110d4bc531 The study design, hypotheses and analytic plan were not preregistered.

Participants

Based on previous studies from our research group (e.g., Taconnat et al., 2009), a total of 130 healthy French younger and older adults living in a medium-sized metropolitan area (Tours, France) were recruited, to ensure having 65 participants per age group.

All older participants lived at home and were recruited from leisure clubs and the Senior Citizens' University. The younger participants were recruited from leisure clubs and through referrals by the older participants. In order to minimize a possible cohort effect and because none of the older adults had a high level of education, none of the younger participants were recruited from higher education institutions. Participants were all volunteers and were individually interviewed to exclude those with a history of alcoholism, undergoing treatment for psychiatric illness, or taking psychoactive medication. The older adults were also screened on the Mini Mental State Examination (MMSE; Folstein et al., 1975), with the cut-off threshold set at 27 points to minimize the risk of including people with pre-clinical dementia. Participants were mostly Caucasian, although this information was not systematically collected. This research was approved by the Ethic Committee of the Department of Psychology from the University of Tours (Title: Corrélats cognitifs des stratégies de mémoire au cours du vieillissement).

No power analysis was run prior to data collection. Nevertheless, we conducted an *a posteriori* sensitive power analysis to interpret near significance effects (see Discussion).

From the total sample, three participants (two younger adults and one older adult) were excluded because they were on medications, two other older adults whose scores at the

MMSE were below 27 points were removed from the sample as well as an additional two older adults whose recall scores did not allow the computation of organizational scores as these scores were too low. Therefore, the final sample consisted of 123 participants with 63 younger adults (aged from 20 to 34 years-old; 33 women) and 60 older adults (aged from 60 to 80 years-old; 35 women). As reported in Table 1, the two groups were matched on their performances on the Mill-Hill vocabulary test (Raven, 2000), number of years of formal education, self-reported health score (measured by using a five-point scale from 0 (bad health) to 5 (very good health) and depression and anxiety scores on the HADS (Hospital Anxiety and Depression Scale; (Zigmond & Snaith, 1983).

Table 1: Demographic characteristics of each age group.

	Younger (n= 63)	**Older (n= 60)**	**t (121)**
Age	25.82 (3.49)	71.5 (3.94)	67.95 ***
Educational level	12.62 (1.83)	11.92 (2.83)	1.63 (p=.107)
Vocabulary	25.31 (3.32)	26.36 (3.42)	1.72 (p=.087)
Subjective Health	3.82 (.90)	3.88 (.88)	.36 (p = .720)
Depression	5.98 (2.53)	6.30 (2.82)	.65 (p=.515)
Anxiety	6.38 (2.70)	5.48 (3.16)	1.69 (p=.093)

Note: *** = $p < .001$

Materials and procedure

The experiment was conducted in two sessions, 3 to 5 days apart depending on the participants' availability, and no participant dropped out of the study. During the first session, participants were screened and interviewed. They performed one of the episodic memory tasks (list of organizable words or list of non-organizable words) and about half of the battery of the cognitive tests. During the second session, they completed the other episodic memory task and the remaining tests from the cognitive test battery. The episodic memory tasks and cognitive tests were counter-balanced across participants.

Episodic memory tasks

Organizable words-based episodic memory task and semantic organization

Participants were shown once a categorized 20-word list (five categories of four words, see Taconnat et al., 2020). The words were arranged and presented in pseudo-random order so that two words from the same category were never presented sequentially. Participants were not informed about the possible structuring of lists. The words for the five categories were selected from a table (Marchal & Nicolas, 2003) which was constructed from category classes generated by young and older adults. The categories were matched with respect to word length, word frequency (Brulex database, (Content et al., 1990) and typicality of semantic category, similar for both younger and older adults. The words were 5-8 letters long, with 2-3 syllables, and were all concrete nouns. The stimuli were presented on a computer screen, for five seconds each. After the list presentation, participants performed a letter comparison task (XO) for 45 seconds. This task served as an interference task to prevent the recency effect. After the XO task, the participants were asked to say as many words as they could recall, and the recalled words were recorded by the experimenter. In this way, any difficulty in writing was avoided, particularly in older adults. The participants were asked to recall the list three times without re-learning it, with 30 seconds between each repetition, with the aim of evaluating the evolution or stability of memory and clustering across time. At the end of encoding and recall, participants relaxed for a few minutes before taking the remaining tests.

The *Adjusted Ratio Clustering* score (ARC) developed by (Roenker et al., 1971) was used as a measure of semantic organization at recall. A score of 0 indicates chance clustering and a score of 1 refers to perfect clustering. It is computed according to the following formula:

$$ARC = \frac{R - E(R)}{maxR - E(R)}$$

"…where R is the total number of category repetitions, max R is the maximum possible number of category repetitions, and E(R) is the expected (chance) number of category repetitions" (Roenker et al., 1971, p. 46).

This adjusts for the differences in total number of items recalled which is important considering that young adults are likely to recall more words than older participants. Thus, ARC scores are relatively independent of the recall score, inasmuch as a low score at recall may lead to a high ARC score if the few words are recalled in an organized fashion.

Non-organizable words based episodic memory task and subjective organization

Participants were shown once a non-categorizable 20-word list comparable to the organizable list with respect to word length and word frequency (Brulex data base, Content et al., 1990, and see Taconnat et al., 2020 for the use of the same list). The same procedure as the organizable words-based episodic memory task was used in respect of the time of presentation of the items, the interference task, and the three free-recall tasks with an interval of 30 seconds between each.

The Pairwise Frequency scores (PF): Subjective clustering across free-recall trials (Anderson & Watts, 2013 ; Sternberg & Tulving, 1977) were calculated according to the following formula:

$$PF = O(ITR) – E(ITR)$$

where O(ITR) corresponds to the number of item pairs recalled commune to 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:

$$E(ITR) = \frac{c(c-1)}{hk}$$

where with *c* corresponding to the number of items recalled both to trial t and trial t+1, *h* corresponding to the total number of words recalled, at trail 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.

The coding of the ARC and PF scores was done by one of the authors, and thus was not blind to the experimental conditions.

Cognitive Assessment

Six cognitive test scores were selected, designed specifically to evaluate different cognitive control and working memory processes. These tests have been chosen as they are classically used by the one hand to assess cognitive control, requiring cognitive control but not storage in memory, and by the other hand, target working memory, because they necessitate both storage and manipulation of the information to be processed.

Cognitive control

Wisconsin Card Sorting Test (WCST; Heaton et al., 1993). This test assesses general cognitive control and was administered and scored according to the standard procedure using a pack of 64 cards. The specific measure retained here was the number of perseverative errors, which are those most affected by age and the most representative of cognitive control (Miyake et al., 2000). Perseveration reflects difficulty in adaptively discontinuing a prepotent response or use of a previously reinforced strategy when its use is no longer beneficial. A high score on this test reflects low performance.

Stroop Color-Word Test (SCWT; (Stroop, 1935). Two sub-tests of the standard SCWT assessing inhibition were used: the color sub-test in which participants have to name the color of crosses (XXX), and the color-word interference sub-test in which they have to name the color of color-words while ignoring the printed word. In each sub-test, participants were required to name colors aloud as quickly as possible for 45 seconds, and the number of correct responses was recorded. Taking the crosses condition as the baseline, scores were transformed into proportion scores for each participant as follows:

$$\frac{(ColourNaming\ score) - (ColourWordInterference\ score)}{ColourNaming\ score}$$

Trail Making Test (TMT; Reitan, 1958). The TMT, which assesses shifting, includes two parts: A and B. In part A, the participants have to connect digits in ascending order. In part B, the participants have to alternately connect letters in alphabetical order and digits in ascending order (e.g., 1A2B3C, etc.). Performance was measured by the time necessary to complete each part of the task. A flexibility score was calculated by applying the following formula:

$$\frac{(Completion\ time\ for\ part\ B) - (Completion\ time\ for\ part\ A)}{Completion\ time\ for\ part\ A}$$

Working memory

N-back task (Kirchner, 1958, Leon-Dominguez et al., 2015). In this task, the participant views 30 letters (consonants) displayed on a computer screen, one at a time. From the third letter, participants had to make decisions (“same” or “different”) about the stimulus they saw ‘‘2-back’’ as each new stimulus was presented. Participants were requested to give their answer verbally, and the experimenter recorded the answers. The score was the number of correct answers.

The Backward Digit Span (Hilbert et al., 2015 ; Wechsler, 2008; Yoshimura et al., 2021).Testing procedure for the Digit Span task was followed according to the standard administration from the Weschler Adult Intelligence Scale (WAIS), that is, strings of digits are read to subjects at a rate of 1 per second and the subject is asked to repeat them orally in the correct sequence (either forward or backward order). The number of digits in each string increases from 2 to 8. The test is stopped when the participant consecutively fails two trials.

Total score corresponded to the maximum number of digits the participant was able to repeat correctly.

The Alpha Span Test (Craik et al., 2018). In this task, 14 lists of common one-syllable words were used. The lists varied in length from 2 to 8 words, and there were two lists of the same length. Presentation started with the list length of two words and increased to one word unless participants failed on both lists of the same length. On each trial, the participant's task was to rearrange the words mentally and recall them orally in alphabetical order. The score was the number of items recalled as a member of a correctly recalled adjacent pair.

Data analyses

Data were analyzed using R version 4.1.0 (Team R Core, 2021). We first analyzed age-related differences on recall (number of words) and ARC and PF using Linear Mixed Model (LMM; Hypothesis 1). First of all, on recall, we fit a LMM with age group (younger adults, older adults) as a between-subjects factor, memory task (organizable, non-organizable) and trial number (1, 2, 3) as within-subject factors and Participants as a random factor. This model was fit with the *lme4* and *afex* packages (Bates et al., 2015; Singmann et al., 2020). We then examined the effects of age group and memory task on semantic organization using the variable ARC as dependent variable. As this variable comprises scores from 0 and 1 and included 0 and/or 1, this was not suitable to be fit using a GLMM with a Binomial distribution. As such, we used a Beta Regression (Ferrari & Cribari-Neto, 2010) and to account for 0 and 1 values, we applied the following transformation:

$$\frac{(y(n-1))+0.5}{n}$$

where n is the sample size (Smithson & Verkuilen, 2006)

This Beta Regression was fit using the *betareg* package (Cribari-Neto & Zeileis, 2010). Following this analysis, we examined the effects of age group and inter-trial (first trial to second trial or 1-2 inter-trial — second trial to third trial or 2-3 inter-trial) – but not trial number as for ARC, given that PF needs at least two trials to be computed – as between-subjects and within-subject factors and Participant as random factor on subjective organization (PF) using another LMM. For all the analyses described above, the package *emmeans* (Lenth, 2020) was used to perform the pairwise comparisons with Tukey adjustments when there were multiplicity issues.

Age-related differences on the different cognitive tests (cognitive control and working memory) were analyzed using t-tests (Hypothesis 2).

We then conducted a Structural Equation Modelling (SEM) analysis using the package *lavaan* (Rosseel, 2012) to examine whether the cognitive tests were representative of cognitive control and working memory (Hypothesis 3). To do so, we fit and compared two SEM models where all cognitive tests (observed variables) accounted for one latent variable (model 1) and where the WCST, SCWT and TMT loaded onto one latent variable (cognitive control) and the N-Back test, Digit Span and Alpha Span loaded onto another latent variable (working memory; model 2). From this analysis, we then took the best model to test how the latent variable(s) was/were predicted of recall in both memory tasks (organizable, non-organizable), semantic organization (ARC) and subjective organization (PF) using a third SEM model (Hypothesis 4). The fit of the different models was assessed using the comparative fit index (CFI) and the Akaike Information Criterion (AIC). The CFI has a value ranging from 0 to 1 that indicates the proportion of improvement in the overall fit of the hypothesized model relative to a null model in which all covariances between variables are zero and this value should be ideally around or greater than .95 (Bentler, 1990 ; Hu & Bentler, 1999).

Finally, we performed multiple linear regressions on the *average scores* of ARC and PF with the cognitive control index and the working memory index as continuous factors and age group as a categorical factor to explore to what extent these indices predicted the use of these two organizational behaviors and whether there were age-related differences (Hypothesis 5). To this aim, we fit two models with these three main factors (cognitive control index, working memory index and age group) as well as the two two-way interactions of interest, which were between cognitive control index and age group and working memory index and age group. We fit the regression models with the *z*-scores of the cognitive control and working memory indices as they provided less collinearity issues than the latent factor scores, which was checked with the function *VIF* from the *regclass* package. For these regression models, we were interested in the main effects of age group, cognitive control index, working memory index and the two two-way interactions between cognitive control index and age group, and working memory index and age group.

Results

Hypothesis 1: Age-related effects on recall

The analyses revealed main effects of age group, $\chi^2 = 63.73$, $df = 1$, $p < .001$, memory task, $\chi^2 = 285.30$, $df = 1$, $p < .001$, and trial number, $\chi^2 = 10.54$, $df = 2$, $p = .005$, on recall. Younger adults recalled more words than older adults ($M_{\text{younger adults}} = 10.30$ *vs*. $M_{\text{older adults}} = 7.10$) and recall was higher in the organizable words memory task than in the non-organizable words memory task ($M_{\text{organizable words}} = 10.21$ *vs*. $M_{\text{non-organizable words}} = 7.21$). Regarding the effect of trial number, participants had a higher recall performance in the first trial than in the two next trials ($M_{\text{first trial}} = 9.07$ *vs*. $M_{\text{second trial}} = 8.56$ *vs*. $M_{\text{third trial}} = 8.50$; $ps < .023$), and no difference was observed between the second and third trials, $p = .954$.

These effects were qualified by a significant two-way interaction between age group and memory task, $\chi^2 = 44.18$, $df = 1$, $p < .001$, revealing that younger and older adults recalled more words in the words organizable memory task than in the words non-organizable memory task (younger adults: $M_{\text{organizable words}} = 12.35$ *vs*. $M_{\text{non-organizable words}} = 8.29$; older adults: $M_{\text{organizable words}} = 8.07$ *vs*. $M_{\text{non-organizable words}} = 6.13$; $ps < .001$), the difference was more pronounced for younger adults than for older adults as evidenced by t-ratios (18.33 *vs.* 8.51). Moreover, in both memory tasks, younger adults recalled more words than older adults, *ps* < .001, but this was especially the case for the organizable memory task (Figure 1).

No other interactions were significant, *ps* > .061.

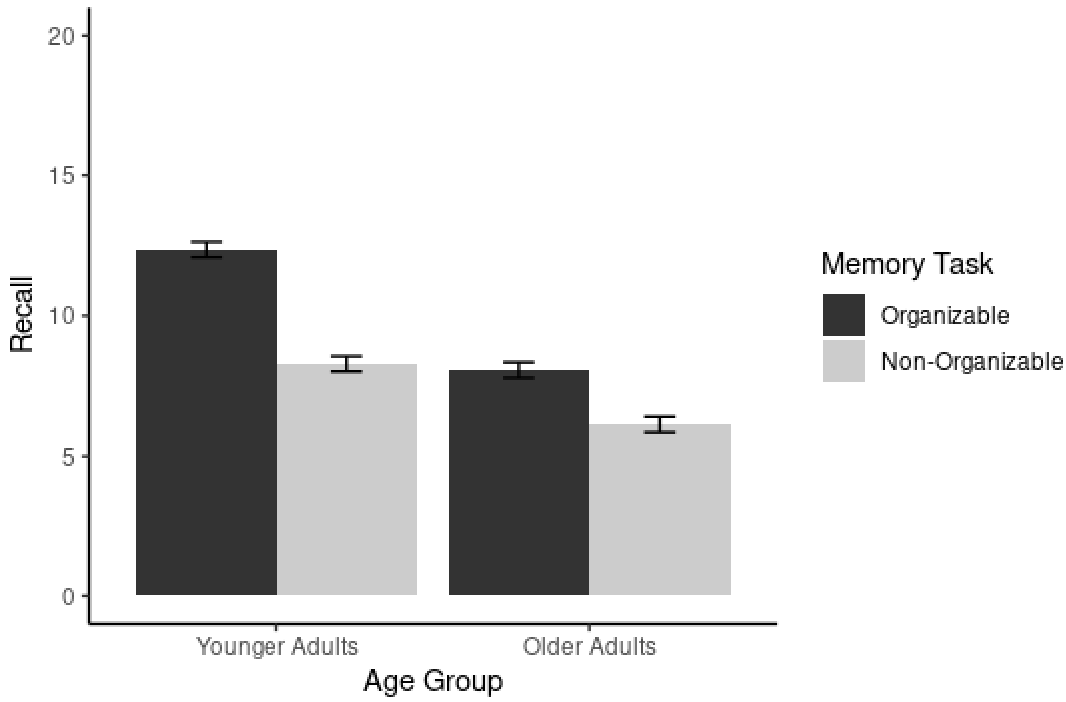

Figure 1. Recall as a function of age group and memory task. Both younger and older adults recalled more words in the words organizable memory task than in the words non-organizable memory task, although this was more pronounced for younger adults.

Hypothesis 1: Age-related effects on ARC

On semantic organization (ARC), there were main effects of both age group, χ^2 = 4.68, *df* = 1, *p* = .030, and trial number, χ^2 = 12.88, *df* = 2, *p* < .001, indicating that younger adults had slightly higher semantic organization than older adults ($M_{\text{younger adults}}$ = .68 *vs.*

$M_{\text{older adults}}$ = .62), and semantic organization was not significantly different from the first to the second, but was significant from the second to the third trial ($M_{\text{first trial}}$ = .60 *vs*. $M_{\text{second trial}}$ = .63 *vs*. $M_{\text{third trial}}$ = .71; p = .502 and p = .036; Figure 2).

The interaction between age group and trial number was not significant, p = .563.

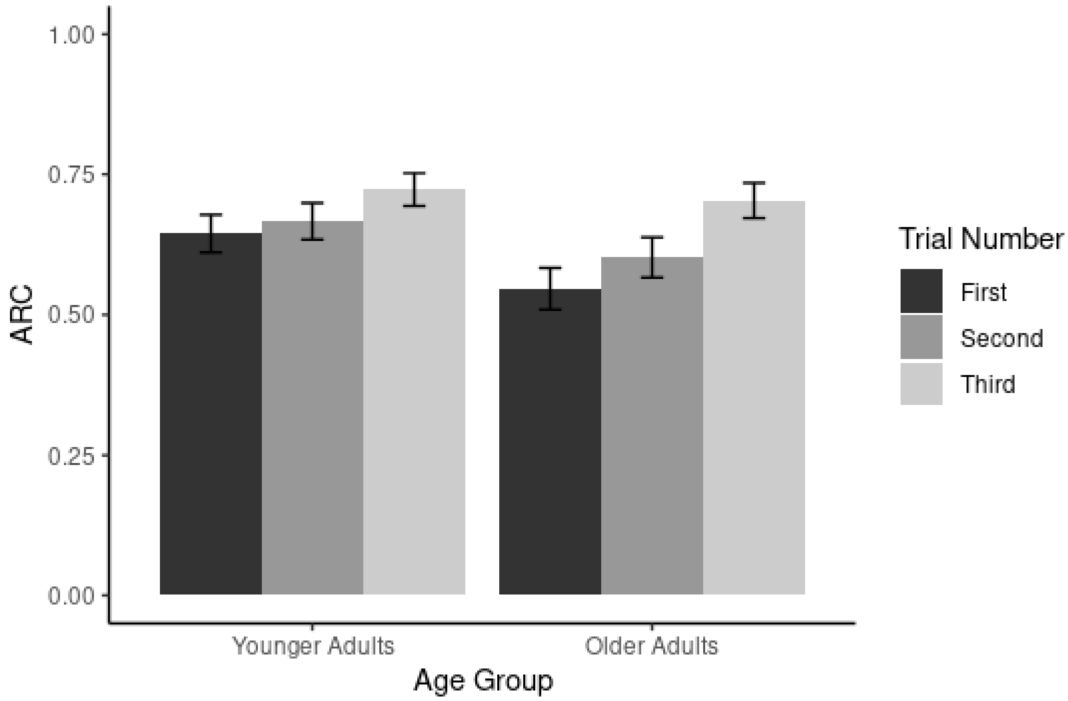

Figure 2. ARC as function of age group and trial number. Semantic organization was slightly higher for younger adults than older adults and was only significantly higher from the second to the third trial.

Hypothesis 1: Age-related effects on PF

On subjective organization (PF), there were main effects of age group, χ^2 = 73.87, *df* = 1, p < .001, and inter trial, χ^2 = 43.13, *df* = 1, p < .001, indicating that younger adults had higher subjective organization than older adults ($M_{\text{younger adults}}$ = 2.17 *vs*. $M_{\text{older adults}}$ = .62), and subjective organization was higher in the 2-3 inter trial than in the 1-2 inter-trial ($M_{\text{1-2 inter-trial}}$ = 1.04 *vs*. $M_{\text{2-3 inter-trial}}$ = 1.76). However, the significant two-way interaction between age group and inter trial, $\chi^2 = 10.32$, $df = 1$, $p = .001$, indicated that subjective organization increased more between inter trial 1-2 and inter trial 2-3 in younger adults than in older adults (younger adults: $M_{1\text{-}2 \text{ inter-trial}} = 1.65$ *vs*. $M_{2\text{-}3 \text{ inter-trial}} = 2.70$; $p < .001$; older adults: ($M_{1\text{-}2 \text{ inter-trial}} = .42$ *vs*. $M_{2\text{-}3 \text{ inter-trial}} = .82$; $p = .007$; Figure 3).

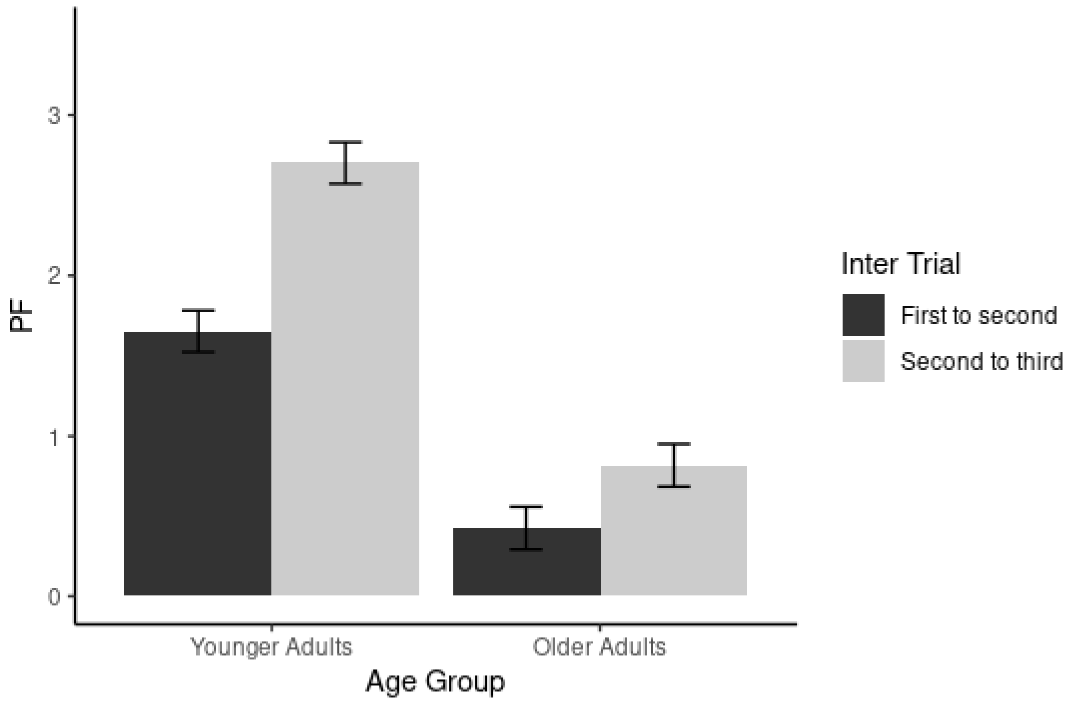

Figure 3. PF score as a function of age group and inter-trial. Both age groups showed higher subjective organization in the second to third inter-trial than in the first to second inter-trial, but this was more pronounced for younger adults than older adults.

Hypothesis 2: Age-related effects on the cognitive tests

As shown in Table 2, the effect of age group was significant on all the cognitive control and working memory measures, which is in accord with the classical pattern of cognitive aging.

Table 2. Comparisons between means (and SD) scores of cognitive control (Perseverative errors for the WCST; the Inhibition Index for the SCWT; the Flexibility Index for the TMT) and working memory (Correct Answers for the N-Back; Number of Digits Correctly Recalled for the Digit Span backward; Total of Items Recalled for the Alpha span) measures in younger and older adults.

	Younger (n=63)	**Older (n=60)**	**t (121)**
Cognitive control			
WCST	8,92 (3,97)	22,36 (16,56)	6,12***
SCWT	0,47 (0,11)	0,60 (0,12)	6,36***
TMT	30,71 (11,12)	74,18(61,09)	5,43***
Working Memory			
N-Back	7,71 (1,49)	5,00 (1,16)	11,31***
Digit Span backward	7,95 (2.14)	5,65 (1,29)	7,28***
Alpha span	7,79 (1,36)	4,85 (1,34)	12,11***

Note: WCST: Wisconsin Card Sorting Test; SCWT Stroop Color-Word Test; TMT: Trail Making Test; *** = $p < .001$

Hypotheses 3 and 4: Structural Equation Modelling analyses

The model fit indices for Model 1 (all variables loading to a single factor) indicate a poor fit to the data: CFI = .855, RMSEA = .300 and SRMR = .197. We therefore ran Model 2 (WCST, SWT and TMT loading onto one cognitive control variable and N-Back test, Digit Span and Alpha Span loading onto another working-memory variable), which showed a better fit to the data (Model 1: AIC = 1552.5, χ^2 = 108.404; Model 2: AIC = 1476.8, χ^2 = 30.609), χ^2 = 77.796, $p < .001$, with better fit indices (Model 2: CFI = .967, RMSEA = .152 and SRMR = .110) and indicated that WCST, SWT and TMT significantly contributed to the cognitive control latent variable (*ps* < .001) whereas the N-Back, Digit Span and Alpha Span contributed significantly to the working memory latent variable (*ps* < .001; see Figure 4).

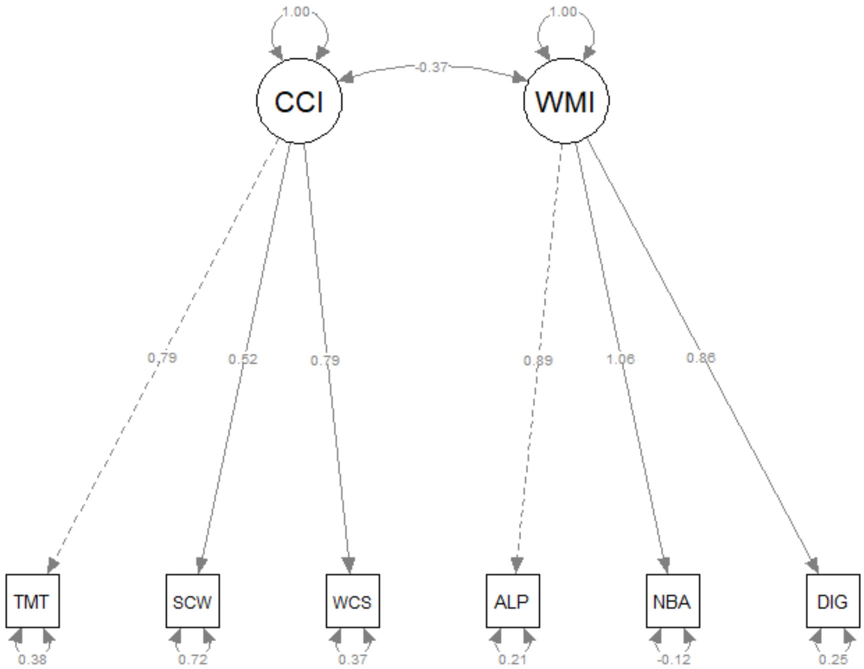

Figure 4. Plot of the SEM model comprising one cognitive control latent index variable (CCI) and another working memory index latent variable (WMI). The dashed line indicates that the loading factors were fixed at a scale of 1.

Based on Model 2, we fit another SEM model (Model 3) where we added the regressions factors of organizable recall, ARC, non-organizable recall and PF to the cognitive control and working memory latent variables. In this model (CFI = .927, RMSEA = .144 and SRMR = .080), organizable recall and ARC were predicted by cognitive control, *z* = -2.47, *p* = .014 and *z* = -2.26, *p* = .024, respectively, but not by working memory, *ps* > .095. Finally, working memory predicted only PF, *z* = 6.82, *p* < .001, but not other regression factors *p*s > .080 (Figure 5).

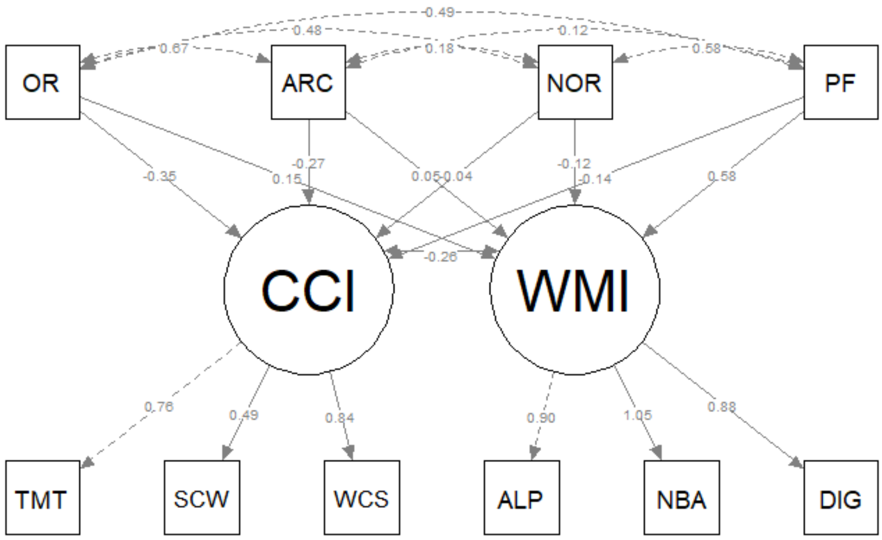

Figure 5. Plot of the SEM model comprising one cognitive control index latent variable (CCI) and another working memory index latent variable (WMI) and the four regression factors organizable recall (OR), ARC, non-organizable recall (NOR) and PF. The dashed line indicates that the loading factors were fixed at a scale of 1.

Hypothesis 5: Regression analyses on semantic and subjective organization

Cognitive control and working memory indices explained a significant proportion of variance in semantic organization (ARC) scores, $R^2 = .18$, $F(5, 117) = 5.41$, $p < .001$. the model revealed a significant main effect of cognitive control index, $F(1,117) = 13.61$, $p = .003$, partial $\eta^2 = .17$, but no other main effects, *ps* > .694, and no significant interactions, *ps* > .083. Overall, the higher their cognitive control abilities, the more participants engaged in semantic organization (ARC), (Figure 6, left panel).

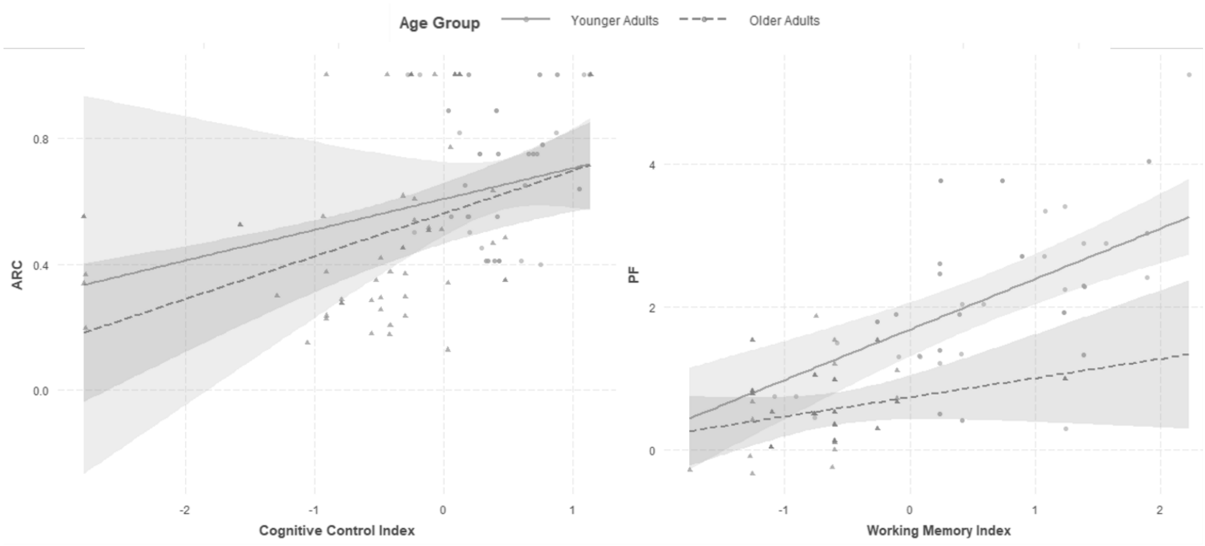

Figure 6. ARC as a function of age group and the cognitive control index (left) and of age group and working memory index (right). ARC was associated with higher cognitive control indices for all participants, and PF tended to be more associated with the working memory index for all participants.

Cognitive control and working memory indices explained a significant proportion of variance in subjective organization (PF scores), $R^2 = .57$, $F(5, 117) = 30.91$, $p < .001$. The model yielded significant main effects of age group, $F(1,117) = 21.30$, $p < .001$, partial $\eta^2 = .15$, and working memory index $F(1,117) = 27.60$, $p < .001$, partial $\eta^2 = .44$, but not of cognitive control index, $p = .327$. This indicated that younger adults ($M = 1.69$) had a higher use of subjective organization than older adults ($M = .74$) and the use of this strategy in both age groups was positively associated with higher working memory indices. No interactions were significant, $ps > .054$.

Discussion

In the present study, we investigated how two organizational strategies (semantic and subjective organization) were underlined by different controlled systems (cognitive control and working memory) and to what extent these relations were subjected to potential age-related effects.

To begin with, in line with our general predictions, we replicated many previous findings with younger adults recalling more words than older adults in the two wordlists (organizable and non-organizable, Hypothesis 1; e.g., Nyberg, 2017; Oschwald et al., 2020; Rhodes et al., 2019) and the former outperforming the latter in all cognitive control and working memory measures (Hypothesis 2; e.g., Braver, 2008; Rhodes et al., 2019). Regarding task-related findings, consistent with the literature, we found that participants recalled more words from the organizable wordlist than from the non-organizable wordlist regardless of their age (Bäckman & Wahlin, 1995; Herlitz & Viitanen, 1991; Sauzéon et al., 2006; Stuss et al., 1996), and there was an overall decrease in recall performance from the first trial to the two next trials (Taconnat et al., 2020).

Regarding organizational behaviors (Hypothesis 1), we observed that younger adults showed both higher semantic and subjective organization than older adults, though with some differences. Indeed, the difference between the two age groups for subjective organization (PF score) was important as already shown in previous studies (e.g., Davis et al., 2013; Hultsch, 1974; Kausler, 1994; Light, 1991; Sauzéon et al., 2006; Stuss et al., 1996; Taconnat et al., 2020; Witte et al., 1990, 1993). Conversely, although the difference between younger and older adults for semantic organization (ARC score) was also significant for the Beta regression analysis, it failed to reach significant for the regression analysis. This was likely since three different ARC scores were inserted in the Beta regression analysis whereas an average of the three different ARC scores was included in the regression analysis. Therefore, these results contributed to the literature with some studies reporting that older adults do use semantic organization spontaneously during recall as much as younger adults (e.g., Bäckman & Wahlin, 1995; Burack & Lachman, 1996; Kahana & Wingfield, 2000; Kuhlmann & Touron, 2016; Park et al., 1989; Rankin et al., 1984; Sauzéon et al., 2006; Taconnat et al., 2020), while other studies indicate a significant age-related impairment in the use of this mnemonic strategy (e.g., Denney, 1974; Howard et al., 1981; Taconnat et al., 2009; West & Thorn, 2001; Zivian & Darjes, 1983). Nonetheless, our findings suggest that there seems to be more impairment in subjective organization than in semantic organization with aging.

Moving on to our main research question, namely regarding the contributions of cognitive control and working memory to different organizational mnemonic strategies and whether it is subjected to age-related differences, the prerequisite for answering this question was that the different cognitive tests evaluating the controlled processes were divided into two factors, one corresponding to cognitive control and the other to working memory. The idea that working memory and cognitive control correspond to distinct processes was based on work using brain-imaging methods (e.g., Owen et al., 1999; 2005) and recent research on individual differences (e.g., Frischkorn et al., 2019; Frischkorn et al., 2022; Rey-Mermet et al., 2019). In link with these previous findings, the SEM analyses revealed that a model yielding two distinct latent factors, respectively one for cognitive control (based on the SWCT, WSCT, TMT, which are tasks that do not include a short-term storage component) and another for working memory (N-Back, Backward Digit Span, Alpha Span tests, which are tasks that include a short term storage component), was better than a single latent factor model (Hypothesis 3). This result supports the fact that these two controlled processes are underpinned by different brain regions. Importantly, based on this dissociation and consistent with our Hypothesis 4, we reported that overall, the cognitive control latent factor predicted semantic organization and the corresponding recall from the organizable wordlist whereas the working memory latent factor sustained subjective organization but was not associated with any recall measures.

These results were confirmed and refined in our regression analyses examining the contribution of cognitive control and working memory to semantic and subjective organization depending on age group. Indeed, in line with the prediction of our Hypothesis 4, our regression analyses revealed that cognitive control was a significant predictor of semantic organization and working memory a significant predictor of subjective organization for both younger and older adults. As such, contrary to what was expected with our Hypothesis 5, we did not find evidence for age-related changes in these two associations as interactions were not significant. However, to better interpret these non-significant interactions, we conducted a sensitive power analysis with G*Power (Faul et al., 2007), setting an alpha power of .80, a total sample size equal to 124 and a number of predictors equal to 5 (three main effects and two interactions). This analysis indicated that with this sample, our design would have been able to detect significant effects with a minimum effect size of f^2 = .11 or partial η^2 = .10. As the effect size of these two interactions were below these minimum effect sizes the design could have detected (partial η^2 = .03), this indicated that the test of these interactions is not informative with our sample size (Lakens, 2022).

However, it is important to note that our results are not consistent with a recent study showing that semantic organization and working memory are related (Cherry et al., 2021). But, this study used another measure of clustering than the ARC score, which was the number of categories among correctly recalled items. As such, the latter measure is heavily dependent on recall performance and might explain the difference between this study and ours. Future investigations should look at how different measures of clustering behaviors are similar or different in order to ensure appropriate comparisons between studies.

To conclude, we investigated for the first time in a single study the age-related respective contribution of cognitive control and working memory processes to two organizational behaviors, semantic and subjective organization, in episodic memory. In line with previous studies, we showed that older adults engaged less semantic organization than younger adults, with a strong reliance on cognitive control capacities in both age groups. While younger adults used more subjective organization than older adults and this strategy was underlined by working memory capacity in both age groups. These results shed new lights on our understanding on how two controlled processes differently contribute to organizational behaviors in episodic memory.

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