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The Role of Articulatory Rehearsal in Short-Term False Memories during Aging

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Abstract

Recent studies have shown that articulatory rehearsal prevents false memories in working memory tasks in young adults. During aging, a substantial increase in false memories has been documented in numerous studies. The aim of the present study was to investigate the role of rehearsal in the increase of false memories with age. In two experiments, we manipulated the opportunity to use rehearsal in a Brown-Peterson task in which younger ($n = 80$) and older ($n = 70$) adults maintained semantically related word lists and reported their maintenance strategies. Both experiments showed that reducing the opportunity to use rehearsal increased false memories and decreased correct recall in both groups. Furthermore, older adults made more false memories and less correct recall than younger adults, and these effects were partially mediated by the number of times participants reported using rehearsal (Exp. 2). These findings suggest that age-related differences in rehearsal use explain differences in working memory task performance.

Keywords: Articulatory Rehearsal, Working Memory, False Memory, Aging

As we age, we are not only more likely to forget past events, but also to remember events that never happened. This increased susceptibility to false memories is thought to be due to changes in the medial temporal lobe and prefrontal cortex, leading to a decline in the ability to access specific episodic memory representations and executive functioning (see Devitt & Schacter, 2016, Greene & Naveh-Benjamin, 2023; for reviews). Most research has examined this phenomenon using tasks that assess the retrieval of information from long-term memory, i.e., minutes, hours, or even days after it was first presented (e.g., Koutstaal & Schacter, 1997; Norman & Schacter, 1997; Spencer & Raz, 1995; Tun et al., 1998). However, studies with young adults have shown that false memories can also emerge within seconds of encoding just a few pieces of information (e.g., Atkins & Reuter-Lorenz, 2008; 2011; Flegal et al., 2010). These studies suggest that the mechanisms that ensure the maintenance of information in the few seconds after it is encoded play an important role in the formation of false memories that has never been considered in studies using long-term memory tasks. In particular, recent research has highlighted the central importance of a working memory (WM) maintenance mechanism, articulatory rehearsal (Abadie & Camos, 2019; Abadie et al., 2023).

Articulatory rehearsal is conceived as a language-based mechanism that operates through the articulatory repetition of phonological traces of items stored in WM (e.g., Baddeley & Hitch, 1974). The use of articulatory rehearsal to maintain information within a few seconds of encoding has been shown to significantly reduce the occurrence of false memories in young adults. WM declines with age, and aging leads to significant changes in the use of WM maintenance mechanisms (Naveh-Benjamin & Cowan, 2023). However, the relationship between the decline in WM and the increase in false memories during aging has never been investigated. Therefore, the aim of the present study was to examine whether age-related changes in the use of articulatory rehearsal could account for the increase in false memories with age.

Age-related Differences in the Occurrence of False Memories

The most widely used paradigm for studying false memories is the Deese, Roediger and McDermott paradigm (DRM, Deese, 1959; Roediger & McDermott, 1995). In this paradigm, participants study several lists of 12 to 15 words that are highly semantically related to each other (e.g., “hill, valley, climb, summit, top, etc.”) as well as to an unrepresented critical lure (e.g., “mountain”). Subsequently, they perform recall and/or recognition tests. When tested after the presentation of each list or multiple lists, participants often falsely recall and/or recognize the critical lure and other unrepresented but semantically related words as having been presented in a high proportion of cases (40-55%), often rivaling the rate of correct recall or recognition (see Gallo, 2010; Chang & Brainerd, 2021, for reviews). Late-life changes in the DRM illusion have been studied extensively (Dennis et al., 2007; Gallo & Roediger, 2003; Kensinger & Schacter, 1999; Koutstaal & Schacter, 1997; Koutstaal et al., 1999; Norman & Schacter, 1997; Tun et al., 1998), and it is well established that susceptibility to the illusion is more pronounced in older adults than in younger adults (see Devitt & Schacter, 2016; Jacoby & Rhodes, 2006; for reviews).

The primary assumption regarding the increase in false memories with age in the DRM paradigm is that older adults would preferentially process the gist or general meaning of the information. They would focus more on the gist/meaning that connects the list items (e.g., "hill, valley, and climb" are all related to the concept of "mountain"), which would increase their susceptibility to false recognition of the critical lure. This view is consistent with the recent proposal that older adults have less specific episodic representations than younger adults (Greene & Naveh-Benjamin, 2023). The ability to access specific representations would be more limited during aging due to poorer encoding, maintenance, or retrieval of these representations, leading older adults to rely on more general representations that are more easily accessible. Several studies support these predictions. For example, Abadie et al. (2021)

showed that older adults have greater difficulty retrieving specific representations of studied items than younger adults, which leads to an increased likelihood of false memories in the DRM paradigm. Conversely, Abadie and Guede (2023) found that the age-related increase in false memories disappeared when the encoding of item-specific verbatim representations was facilitated by repeated presentation of the same items.

The mechanisms underpinning age differences in the specificity of memory representations, however, have not been clearly elucidated. Some studies have highlighted the role of differences in encoding processing time on episodic memory performance (Lee et al., 2012; Verhaeghen & Salthouse, 1997), while others have pointed to changes in the prefrontal cortex leading to a decline in executive functions (Bugaiska et al., 2007; McCabe et al., 2010). McCabe et al. (2010) demonstrated the critical role of WM and executive functions in episodic memory retrieval. Although recent studies suggest that the transformation of representations that give rise to false memories may occur precisely during the period of information maintenance in WM (e.g., Abadie & Camos, 2019), the interaction between WM maintenance mechanisms and the occurrence of false memories has rarely been investigated.

The Role of Working Memory in the Occurrence of False Memories

Only a handful of studies have examined the occurrence of semantic errors in WM tasks. This can be explained by the fact that semantic coding has historically been considered a signature of long-term memory, while WM models have emphasized the processing of lower-level phonological codes (Baddeley, 1966; Baddeley & Dale, 1966; Baddeley & Levy, 1971). However, studies have shown that in young adults, false memories can actually occur within seconds of studying just a few words. Coane et al. (2007) were the first to report relatively high false alarm rates (20-22%) for semantically related words and longer reaction times for their correct rejection in a recognition task with 5- to 7-item DRM lists administered after a retention interval of approximately 1s. These findings and those of

subsequent studies (Atkins & Reuter-Lorenz, 2008; Atkins et al., 2011; Flegal et al., 2010; 2014) suggest that false recognition errors can reliably occur within the temporal (i.e., after a few seconds of retention) and set size (i.e., for short memory lists) parameters characteristics of WM. Consistent with models that conceptualize WM as the activated part of long-term memory (e.g., Cowan et al., 2021), the authors proposed that false memories may arise from semantic processing mechanisms that are common to both WM and long-term memory.

Other studies have gone further and sought to understand the precise WM mechanisms that contribute to the occurrence of these short-term false memories. Two main mechanisms for maintaining information in WM have been described: articulatory rehearsal and attentional refreshing (Camos, 2015; 2017). Articulatory rehearsal, first conceptualized in Baddeley's (1986; 2007) model, is seen as a language-based maintenance mechanism that can only be used to maintain verbal information. It operates through articulatory repetition of the phonological traces of verbal items that are temporarily stored in a phonological loop. Attentional refreshing, on the other hand, is thought to reactivate memory traces in an executive loop by paying attention to them. These traces are considered to be domain-general, as any type of information, verbal or non-verbal, can be maintained via the use of refreshing (Camos et al., 2018). Numerous behavioral, developmental and neuroimaging studies have shown that attentional refreshing and articulatory rehearsal are two independent processes (e.g., Camos et al., 2009; 2011; Smith & Jonides, 1999; Trost & Gruber, 2012).

Abadie and Camos (2019) investigated the role of each of these two mechanisms in the occurrence of short-term false memories in young adults. The paradigm was similar to that used in previous studies (e.g., Atkins & Reuter-Lorenz, 2008). However, the attentional demand of the concurrent task performed during the retention interval was varied to manipulate the opportunities to refresh the items to be remembered. In addition, to vary the opportunities to use articulatory rehearsal, the concurrent task was performed either aloud to

hinder its use (i.e., articulatory suppression), or silently, which leaves more opportunities for using it. The results showed that articulatory suppression increased false recognition of semantically related distractors in a recognition test administered immediately after the concurrent task. By contrast, varying the attentional demand of the concurrent task had no effect on short-term false recognition of related distractors. Other studies using a short-term variant of the DRM paradigm have also reported an increase in false alarms for semantic distractors under articulatory suppression in recognition (Atkins et al., 2011; Macé & Caza, 2011) and recall tasks (Abadie et al., 2023). In addition, the quality of the representations retrieved was also examined in Abadie and Camos' (2019) study. The results showed that hindering the use of articulatory rehearsal reduced the retrieval of specific verbatim representations and increased the reliance on gist representations, which favored the occurrence of short-term false memories.

These findings suggest that the use of articulatory rehearsal could reduce the occurrence of false memories in young adults by increasing the specificity of retrieved representations. Other studies have shown that short-term false memories emerge very early in childhood and their incidence decreases in older children who use WM mechanisms more effectively (Abadie & Rousselle, 2023; Rousselle et al., 2023). As the use of WM maintenance mechanisms evolves during aging, it seems important to examine their impact on the increase in false memories in old age.

Age-related Changes in the Use of Articulatory Rehearsal

A recent literature review showed that the decline in WM during aging appears to be related to a decline in executive function, a reduction in attentional resources, or a decrease in information processing, which would affect the encoding of information in WM (Naveh-Benjamin & Cowan, 2023). There is no evidence for an age-related loss of storage capacity in the phonological loop. Some studies have suggested that the decline in processing speed with

age may lead to a reduction in the speed at which words can be rehearsed, which could lead to a reduction in WM capacity (e.g., Kinette et al., 1990). However, studies that have specifically examined the effect of aging on the use of articulatory rehearsal have reported mixed results.

On the one hand, some studies have shown that the use of articulatory rehearsal is relatively unaffected by aging. Loaiza and McCabe (2013) examined the effect of aging on the use of articulatory rehearsal by comparing the recall performance of younger and older adults in an operation span task. Participants were asked to maintain lists of four unrelated words while verifying multiplication problems for later immediate and delayed recall. Opportunities to use articulatory rehearsal were varied during the mathematical verification task. Results showed that constraining articulatory rehearsal reduced immediate recall performance in both younger and older adults, suggesting that both age groups use this mechanism, which does not appear to be impaired by aging. However, when asked about the maintenance strategies they used, older adults reported using rehearsal less frequently than younger adults. Hering et al. (2019) also showed that articulatory rehearsal is still used spontaneously and effectively during aging. In this study, a large proportion of old-older adults (aged 75 and older) reported spontaneous use of articulatory rehearsal in WM tasks, and they benefited from instruction to use it when they did not do so spontaneously. In addition, studies have reported that the use of word maintenance strategies (including rehearsal) in WM tasks is age-invariant and therefore cannot account for age-related differences in memory performance (Bailey et al., 2009). On the other hand, other studies have shown a decrease in the efficiency and use of articulatory rehearsal during aging. Chevalère et al. (2020) showed that rehearsal was the most commonly used strategy for word maintenance in complex span tasks. However, younger adults reported using it more than older adults. Other studies have reported similar findings showing a decrease in articulatory

rehearsal efficiency in older adults, either in terms of speed, frequency, or distribution of rehearsals, which contributes to age-related differences in WM performance (Dasi et al., 2008; Multhaup et al., 1996; Ward & Maylor, 2005).

Although it is not yet completely clear whether or not rehearsal is strongly affected by age, it appears that age-related changes in its use may occur. It is possible that interindividual differences in the use of the mechanism and methodological differences between studies may account for the discrepancies in results. The central and protective role of articulatory rehearsal in the occurrence of short-term false memories in young adults raises questions about the impact of age-related changes in its use on the increase in false memories with age.

The Present Study

Two experiments were conducted to examine the role of articulatory rehearsal in the increase in false memories with age. Opportunities for rehearsal were manipulated during a few seconds retention interval of a Brown-Peterson task in which younger and older adults had to maintain short DRM-type word lists. The retention interval was filled with an attentionally demanding concurrent task designed to capture participants' attention and force them to prioritize the use of articulatory rehearsal to maintain the words. This task was performed either silently or under articulatory suppression to allow or reduce opportunities for rehearsal. Participants were then asked to recall the words immediately after completing the concurrent task. Although previous short-term false memory studies have mainly used recognition tasks, a recall task was used in the present study because recall tasks require more active maintenance of items in WM than recognition tasks (i.e., Abadie et al., 2023). Manipulation of articulatory rehearsal is more likely to be effective in cases where information must be actively maintained.

First, based on previous studies showing age-related increases in false memory in DRM-type tasks (e.g., Chang & Brainerd, 2021), we expect older adults to produce more false

memories, i.e., to recall more semantically related unpresented words, in our short-term variant of the DRM task than younger adults. The latter should also have better correct recall performance than older adults (e.g., Naveh-Benjamin & Cowan, 2023). Furthermore, as recent studies have shown (e.g., Abadie & Camos, 2019), we expect younger adults to benefit from opportunities to use articulatory rehearsal, which should increase correct recall and specifically decrease the occurrence of false memories compared to when opportunities to use articulatory rehearsal are reduced. In older adults, manipulating opportunities to use articulatory rehearsal should have the same effect as in younger adults if, as some studies suggest (e.g., Loaiza & McCabe, 2013), this mechanism is preserved from the effects of aging. Conversely, if aging reduces the frequency of use or effectiveness of rehearsal, as other studies suggest (e.g., Ward & Maylor, 2005), then recall performance (correct recall and false memories) in older adults should not be affected by rehearsal manipulation.

Second, during recall, we asked participants to report their subjective experience associated with each of the recalled words according to the scale proposed by Abadie et al. (2023) and tested with young adults. This scale assesses the type of memory traces likely to underlie correct and incorrect recall. Participants were asked to judge the extent to which their recall was associated with the retrieval of precise, specific, or fuzzier memory traces based on the retrieval of general meaning. Consistent with the literature on the effect of age on the specificity of representations (e.g., Greene & Naveh-Benjamin, 2023), we expect that younger adults will report retrieving more specific traces than older adults. For younger adults, the use of articulatory rehearsal should favor the retrieval of specific traces relative to when its use is hindered (e.g., Abadie & Camos, 2019). If they use articulatory rehearsal spontaneously, the same effect should be observed in older adults, whereas if they do not use it spontaneously, the manipulation of rehearsal opportunities should have no effect on their judgments.

Finally, we also asked participants at the end of the experiment (Experiment 1) or after each trial (Experiment 2) to indicate the maintenance strategies they thought they had used. We predict that both younger and older participants will report greater use of articulatory rehearsal in the condition where they have more opportunities to do so, especially if the mechanism is unaffected by aging. On the other hand, if the mechanism is affected by aging, we expect older adults to report preferential use of other types of strategies, such as semantic strategies, due to the nature of the lists, independent of the rehearsal manipulation. The predictions and the main results obtained are summarized in Table 1.

Table 1

Summary of predictions and main results for recall accuracy, subjective experience and strategies used in Experiments 1 and 2.

Predictions	Experiment 1	Experiment 2
Correct recall		
YA better correct recall than OA	✓	✓
Reducing the opportunity to use rehearsal reduces correct recall in YA	✓	✓
In OA, reducing the opportunity to use rehearsal	✓	✓
reduces correct recall	✓	✓
has no effect on correct recall	✗	✗
Semantic errors		
OA make more semantic errors than YA	✗	✓
Reducing the opportunity to use rehearsal increases semantic errors in YA	✓	✓
In OA, reducing the opportunity to use rehearsal	✓	✓
increases semantic errors	✓	✓
has no effect on semantic errors	✗	✗
Subjective experience		
Reducing the opportunity to use rehearsal reduces the retrieval of specific traces in YA	✓	✓
In OA, reducing the opportunity to use rehearsal	✓	✓
reduces the retrieval of specific traces	✓	✓
has no effect on the retrieval of specific traces	✗	✗
Strategy use		
YA report greater use of rehearsal when they have more opportunities to use it	✓	✓
OA report greater use of	✗	✗
rehearsal when they have more opportunities to use it	✗	✗
other types of strategy, despite opportunities to use rehearsal	✓	✓

Note. ✓ indicates there was evidence for the prediction, and ✗ indicates that there was evidence against the prediction. YA is for younger adults and OA is for older adults.

Experiment 1

Method

Ethics and Sample Size

All the experiments were conducted in accordance with the recommendations of the Declaration of Helsinki. Study procedures were approved by the Aix-Marseille University Institutional Review Board (2022-01-13-002), and all participants gave written informed consent prior to participation.

Based on the effect size of manipulating opportunities to use articulatory rehearsal on short-term false recognition (corrected score) in young adults (Cohen's $d = 1.18$) in Abadie and Camos' study (2019, comparison between Exp. 2 and 4), a power analysis indicated that 12 participants per age group would be needed to achieve 95% power (G*Power, Faul et al., 2009). For both experiments, we decided to systematically recruit more than 20 participants per age group, given our time constraints for testing, to accommodate for potential data loss (e.g., participants below the critical threshold at the screening test). Nevertheless, we performed Bayesian analyses in which evidence of a null effect is equally informative (Kruschke, 2011, 2018), and Type I error does not increase with optional stopping (Rouder, 2014).

Participants

Sixty-one participants, 35 younger adults and 26 older adults were recruited from Aix-Marseille University and the surrounding community on a voluntary basis. Participants were native French speakers. All participants reported being in good health, with normal or corrected-to-normal hearing and vision. The Montreal Cognitive Assessment (MoCA, Nasreddine et al., 2005) was administered to older adults to screen for signs of abnormal cognitive decline. Data from one older adult were omitted as they scored below the standard 26-point threshold on the MoCA. The final sample thus comprised 35 younger adults aged 18-

29 and 25 older adults aged 60-80. Demographic measures for the younger and older adult samples are presented in Table 2. There was no difference in the proportion of women and years of education between the two age groups ($BF_{10} = 0.62$, $BF_{10} = 0.42$, respectively).

Table 2

Demographic Information for the Younger and Older Adult Samples.

Experiment	Demographic measure	Younger adults	Older adults
	<i>n</i>	35	25
1	<i>n</i> females (% of sample)	27 (77.14)	15 (60)
	Age <i>M</i> (<i>SD</i>)	20.66 (2.38)	68.16 (4.6)
	YoE <i>M</i> (<i>SD</i>)	13.91 (1.95)	13.24 (3.1)
	MoCA <i>M</i> (<i>SD</i>)	-	28.35 (1.47)
	<i>n</i>	45	45
2	<i>n</i> females (% of sample)	23 (51.11)	32 (71.11)
	Age <i>M</i> (<i>SD</i>)	22.13 (3.17)	68.44 (4.53)
	YoE <i>M</i> (<i>SD</i>)	13.47 (1.59)	12.04 (4.05)
	MoCA <i>M</i> (<i>SD</i>)	-	28.89 (1.44)

Note. YoE = years of education from primary school; *M* = mean; *SD* = standard deviation

Materials

Word Lists. We selected 20 semantically related lists of words from the verbal association norms for concrete French nouns (Bonin et al., 2013). Each list was composed of an unrepresented critical lure (e.g., “bee”) and four associates (e.g., “honey, hive, wasp, hornet”). The mean association strength between the critical lure and the words in each list was high ($M = .81$, $SD = .06$) for the selected lists. None of the lists shared common words or highly related semantic association. The 20 lists were then separated into two groups of 10 lists that were equated in mean associative strength ($BF_{10} = .31$).

Concurrent Task. We adapted the spatial fit task from Vergauwe et al. (2009). We created a set of 60 items. Each item consisted of a black horizontal line and two black square dots. The horizontal line, displayed in the center of the screen, was 7 mm high, and the dots, positioned on the same horizontal plane as each other, measured 7 mm each side. The length of the line could vary from 11 mm to 181 mm and the distance between the two dots also varied, from 7 mm shorter than the line to 7 mm longer than the line. For half of the items, the

dots were presented above the line, and for the other half, they were presented below the line. The line could fit between the dots for half the items and could not fit between them for the other half.

Subjective Experience. During the recall phases, following the procedure used in the study by Abadie et al. (2023), participants were asked to indicate for each word recalled whether they thought it was one of the words studied (i.e., a “studied” response), whether they were familiar with the gist or the meaning of the recalled word but were unsure whether it was a studied word or a word semantically related to one of the studied word (i.e., a “studied or related” response), or whether they had recalled a word at random (i.e., a “guess” response). This scale was used to grasp the level of specificity of the memory. Drawing on the distinction between precise, specific and fuzzier representations based on the retrieval of general meaning (e.g., Brainerd & Reyna, 2023), we assumed that a “studied” response could be associated with the retrieval of a precise memory trace, a “studied or related” response with a fuzzier, meaning-based memory trace, and a “guess” response with a guess.

Procedure

Experiment 1 was presented on a computer using the E-Prime Go software (Psychology Software Tools, Pittsburgh, PA). All data were collected and stored on a laboratory computer. The experiment took place in a quiet room in the presence of the experimenter. Participants were first informed that they would be presented with lists of words they would need to remember for an immediate recall test and a delayed recall test. Each trial started with the sequential presentation of four semantically related words for 1000 ms each for younger adults and 1200 ms each for older adults (Figure 1). To determine the presentation time of each word for each age group, a pilot experiment was conducted with younger ($n = 10$) and older ($n = 8$) adults who had not participated in the experiment, in which they were asked to read each of the words used in the experiment ($n = 240$) as quickly and as

accurately as possible, one at a time. The mean word reading time for older adults was significantly higher ($M = 1171$, $SD = 128$) than for younger adults ($M = 1059$, $SD = 93.5$; $t(16) = 2.15$, $p = .024$). Therefore, in the experiment, the presentation time of each word was adjusted to the mean reading time of each age group.

After word presentation, participants completed the spatial fit task for 8000 ms. They had to judge as quickly and accurately as possible whether or not the horizontal line could fit between the two square dots, pressing the “S” key for no and the “L” key for yes. Younger adults were asked to judge six items, each displayed for 834 ms followed by a 500 ms inter-stimulus interval (ISI), and older adults were asked to judge four items, each displayed for 1500 ms followed by a 500 ms ISI. These parameters were determined in the pilot study in which we measured the total number of spatial fit items achievable for each age group in 8000 ms using the same procedure as Rhodes et al. (2019). Participants started the procedure with a series of three trials of three spatial fit items to be judged in 8000 ms. If the average performance was at least 80% in terms of judgment accuracy, they proceeded to four items, and so on, until they failed to reach the threshold on one series. If they failed a series (e.g., four items), they started again with the lower number of items (i.e., three items). If they failed a second time with the higher number of items (e.g., four items), the procedure stopped, and we assumed that the maximum number of items they could judge in 8000 ms was the one for which they had passed the series of three trials twice. Younger adults were able to judge significantly more spatial fit items in 8000 ms ($M = 6$, $SD = .74$) than older adults ($M = 4$, $SD = .76$, $t(16) = 5.37$, $p < .001$).

Half of the trials were performed under articulatory rehearsal suppression (articulatory suppression condition). Participants were asked to rehearse the syllables “ba-bi-boo” continuously during the spatial fit task. This concurrent articulation was initiated by a 150 ms tone that sounded during a 500 ms interval between the presentation of the last word and the

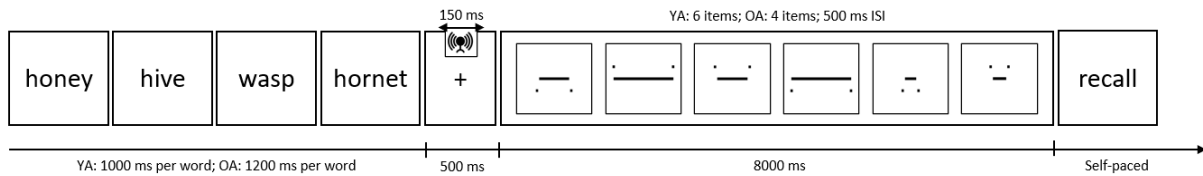
first spatial fit item when a fixation cross appeared in the center of the screen. The other half of the trials were performed without articulatory suppression (no articulatory suppression condition). Participants performed the spatial fit task in silence. Immediately after performing the spatial fit task, participants were prompted to recall the four words. A subjective experience judgment was to be associated with each recalled word. Recall responses and subjective judgments were given orally to the experimenter. There were ten trials per articulatory suppression condition.

At the end of each condition, participants were asked to count backwards by twos from a randomly chosen number between 100 and 1000 for 1 min. They were then instructed to orally recall the 40 words they had just studied in the condition preceding the countdown and to associate a subjective judgment with each recalled word. The results of this delayed recall task, which are not central to the hypotheses tested in the present study, are available at the OSF project [<https://doi.org/10.17605/OSF.IO/EJF52>]. There were no time limits on the recall phases. Each participant completed both conditions, the order of which being counterbalanced across participants. At the end of the experiment, participants were asked about the maintenance strategies they had used in each condition. The experimenter asked them orally, “how did you remember the words?” and specified the condition. Their responses were precisely recorded by the experimenter.

Prior to the experiment, all the participants underwent a training phase that included practice of the spatial fit task alone ($n = 8$ trials) and of the task as a whole ($n = 4$ trials before each condition). During this phase, the experimenter ensured that participants understood the instructions and that they mastered the use of subjective judgments. Finally, demographic information concerning the participants’ date of birth was collected using an input box, gender using a drop-down menu with three options (i.e., female, male and other) and they indicated their years of education.

Figure 1.

Illustration of experimental procedure for Experiment 1.



Note. YA is for younger adults and OA is for older adults.

Results

Bayesian analyses were conducted on concurrent task accuracy, recall accuracy and reported strategy use with age group (younger vs. older adults) as a between-subjects factor and articulatory suppression (articulatory suppression vs. no articulatory suppression) as a within-subjects factor using JASP version 0.17.3 (JASP Team, 2023). In Bayesian hypothesis testing, the strength of evidence for a specified model (M1) was quantified by comparing this model against a null or reduced model (M0). The ratio of the likelihood of the two models under comparison is the Bayes Factor (BF_{10}). BF_{10} of each model was obtained by comparing it to the null model. Strength of evidence is evaluated using Kass and Raftery (1995) interpretation of Bayes Factors. First, we reported the best model, the model with the largest BF_{10} . Then, we report the $BF_{inclusion}$ value for each factor included in the best model (i.e., a main effect or an interaction effect) which indicates the likelihood of the data under models that included a given factor compared to all models stripped of the factor.

Concurrent Task Accuracy

The null model was the best indicating that neither age group nor articulatory suppression condition had any impact on performance on the concurrent task. The mean performance of younger ($M = 77.93$, $SD = 15.78$) and older adults ($M = 84.45$, $SD = 12.63$) was high, indicating that all participants performed the task correctly.

Recall Accuracy

Two independent and trained raters classified the responses to the recall test (i.e., correct recall, semantic errors, phonological errors, intrusions from previous lists or previous recall, other unrelated errors). As in previous studies (Abadie et al., 2023; Atkins et al., 2008), the recall of an unrepresented word semantically related to the theme of the studied list was considered a semantic error (i.e., a false memory), and recall of a word phonologically related to one of the words of the list studied was considered a phonological error. Interrater agreement was high before discussion among raters (unweighted $\kappa = .97$) and full interrater agreement was obtained after discussion. Table 3 shows the percentages of each type of response as a function of age group and articulatory suppression.

Correct Recall. The additive model with main effects of articulatory suppression and age was the best ($BF_{10} = 2.51 \times 10^{12}$). As predicted, articulatory suppression reduced correct recall compared to the no-articulatory suppression condition ($BF_{incl} = 9.22 \times 10^{10}$). Moreover, younger adults had better correct recall performance than older adults ($BF_{incl} = 57.61$). Finally, the analysis of effects provided substantial evidence against an interaction between age and articulatory suppression ($BF_{incl} = 0.26$), suggesting that the opportunity to use articulatory rehearsal is beneficial for correct recall in both younger and older adults.

Recall Errors. As shown in Table 3, the proportion of non-semantic errors (i.e., phonological errors, intrusions and other errors) was very small. Therefore, we aggregated them for the following analyses and added the type of errors (semantic vs. non-semantic) to the Bayesian analysis. The model including the main effects of articulatory suppression, error type and age, as well as the interactions between articulatory suppression and error type and between error type and age was the best ($BF_{10} = 9.19 \times 10^{23}$). However, it was only preferred by a factor of 0.97 to the second-best model, which did not include the interaction between error type and age. The main effects of articulatory suppression and age on recall errors were the simple counterpart of their effects on correct recall. Semantic errors were more frequent

than non-semantic errors ($BF_{incl} = 2.10 \times 10^5$). There was decisive evidence in favor of the interaction between articulatory suppression and error type ($BF_{incl} = 5.81 \times 10^8$). Paired-sample Bayesian t-tests were performed separately for each type of error with articulatory suppression as a within-subjects factor to decompose this interaction. The analyses provided decisive evidence that semantic errors were more frequent in the articulatory suppression condition than in the no-suppression condition ($BF_{10} = 9.17 \times 10^{10}$), while the evidence for an effect of articulatory suppression on non-semantic errors was weak ($BF_{10} = 2.3$). These results replicate those obtained in previous studies (e.g., Abadie & Camos, 2019; Abadie et al., 2023; Atkins et al., 2011; Macé & Caza, 2011) showing an increase in semantic errors when the opportunity to use articulatory rehearsal is reduced. Analysis of the effects provided weak evidence against an interaction between articulatory suppression, error type, and age ($BF_{incl} = .61$), showing that the effect of rehearsal on semantic errors was present in both younger and older adults.

Table 3.

Percentage of correct recall and recall errors (semantic errors, phonological errors, intrusions and other errors) as a function of age group and articulatory suppression condition in Experiment 1.

Age group	Articulatory suppression	Correct Recall	Semantic errors	Phonological errors	Intrusion errors	Other errors
Younger adults	Suppression	90.6 (6.5)	7.1 (5.0)	.10 (.40)	.80 (1.6)	.90 (2.4)
	No suppression	98.4 (2.2)	1.1 (1.6)	.10 (.40)	.40 (.90)	0
Older adults	Suppression	85.3 (9.1)	11.6 (7.4)	.10 (.50)	1.3 (4.1)	1.5 (3.4)
	No suppression	93.4 (6.2)	4.2 (3.8)	.20 (.70)	1.5 (3.4)	.50 (2.0)

Note. Standard deviations are in brackets. The percentage of each type of response corresponds to the average number of responses of each type out of the total number of words to be recalled. Participants could also recall the same word more than once during a trial. Correct and incorrect repetitions of the same word were not counted.

Subjective Experience. We also performed the same analyses as above for correct recall, semantic recall errors and non-semantic recall errors, including subjective experience as a within-subjects factor. Table 4 shows the percentage of each type of subjective judgment for each type of recall as a function of age group and articulatory suppression condition. The main results pertaining to the hypotheses are summarized below. Additional analyses are available at the OSF project [<https://doi.org/10.17605/OSF.IO/EJF52>].

For correct recall, when judgment type (studied vs. studied or related vs. guess) was included in the analysis, the main effect of judgment type as well as the interactions between judgment type and articulatory suppression and judgment type and age were added to the best model ($BF_{10} = 2.32 \times 10^{171}$). In summary, studied judgments were more frequently associated with correct recall ($BF_{incl} = 1.27 \times 10^{127}$). They were more frequent in the no articulatory suppression condition, whereas the other two types of judgments were more frequent in the articulatory suppression condition ($BF_{incl} = 7.11 \times 10^{40}$), suggesting that retrieved representations were more specific when the opportunities to use rehearsal were greater. Younger adults made more studied judgments associated with correct recall, while there was no age-related difference in the percentage of other types of judgments ($BF_{incl} = 3.89$). This finding is consistent with the decrease in specificity of representations with age (e.g., Greene & Naveh-Benjamin, 2023). There was substantial evidence against the interaction between judgment type, articulatory suppression and age ($BF_{incl} = .22$) suggesting that articulatory suppression had the same effect on the quality of representations regardless of participants' age.

As shown in Table 4, semantic recall errors were more often associated with guess judgments ($BF_{incl} = 13.1$). Non-semantic recall errors were more often associated with guess and studied judgments than studied or related judgments ($BF_{incl} = 3.62$).

Table 4.

Percentage of each type of subjective judgment (studied vs. studied or related vs. guess) associated with correct recall, semantic and non-semantic errors as a function of age group and articulatory suppression condition in Experiment 1.

			Subjective judgment		
	Age group	Articulatory suppression	Studied	Studied or related	Guess
Correct recall	YA	Suppression	85.29 (7.27)	4.57 (4.83)	.86 (1.71)
		No suppression	97.14 (3.49)	1.21 (2.93)	0
	OA	Suppression	81.60 (9.01)	2.90 (3.93)	.80 (1.39)
		No suppression	92.40 (6.47)	7.0 (1.15)	.30 (1.1)
Semantic error	YA	Suppression	2.07 (2.74)	2.0 (2.56)	3.0 (3.2)
		No suppression	.21 (.93)	.43 (.96)	.50 (1.01)
	OA	Suppression	2.6 (3.02)	3.4 (4.01)	5.5 (4.21)
		No suppression	1.2 (2.41)	.80 (1.57)	2.0 (2.6)
Non-semantic error	YA	Suppression	.29 (.81)	.14 (.59)	1.29 (2.80)
		No suppression	.21 (.71)	.14 (.59)	.07 (.42)
	OA	Suppression	.5 (1.77)	.30 (0.83)	2.10 (4.31)
		No suppression	1.0 (3.15)	.4 (1.18)	.80 (2.13)

Note. Standard deviations are in brackets. YA is for younger adults and OA is for older adults.

The percentage of each type of subjective judgment corresponds to the average number of responses of each type of judgment for a given response type (correct recall, semantic errors or non-semantic errors) out of the total number of words to be recalled. Participants could also recall the same word more than once during a trial. Correct and incorrect repetitions of the same word were not counted.

Strategy Reports

Reported Strategy Use. Two independent and trained raters classified the maintenance strategies reported by the participants according to the classification proposed by Chevalère et al. (2020). Four main strategies were observed: a phonological strategy consisting in rehearsing the words to be remembered, a semantic strategy consisting in grouping several

words belonging to the same list on the basis of their common semantic features, a phono-semantic strategy consisting in combining the phonological and semantic strategies, and other strategies relying on aspects of the words other than phonology or semantics (e.g., such as imagery). Moreover, some participants reported that they had not used any strategies to maintain the words. Interrater agreement was high before discussion among raters (unweighted $\kappa = .94$) and full interrater agreement was obtained after discussion. Table 5 shows the percentage use of each type of strategies as a function of age group and articulatory suppression condition.

We conducted a Bayesian analysis to examine the effects of articulatory suppression and age on strategy reports, including strategy type as a within-subjects factor. The full model, including all main effects and interactions, was the best ($BF_{10} = 7.97 \times 10^{34}$). There was decisive evidence for the effect of strategy type ($BF_{incl} = 8.96 \times 10^{13}$). Post-hoc comparisons indicated that the semantic strategy was reported more frequently than the others ($BF_{10s, U} > 122$). The phonological strategy was reported more often than phono-semantic ($BF_{10, U} = 41.2$) and other strategies ($BF_{10, U} = 98$), but not more often than the absence of strategy ($BF_{10, U} = .24$), whose frequency also did not differ substantially from that of phono-semantic ($BF_{10, U} = 2$) and other strategies ($BF_{10, U} = 1.11$). Effects analysis provided substantial evidence against the main effects of articulatory suppression and age ($BF_{incls} < .11$). However, the three-way interaction between articulatory suppression, age, and strategy type was strongly supported ($BF_{incl} = 28.8$). To decompose the interaction, Bayesian analyses with articulatory suppression and age as factors were conducted separately for each strategy.

For the phonological strategy reflecting the (reported) use of articulatory rehearsal, the full model was the best ($BF_{10} = 5.67 \times 10^9$). As expected, participants reported using the phonological strategy more often in the no-articulatory suppression condition than in the articulatory suppression condition ($BF_{incl} = 4.49 \times 10^7$). Moreover, younger adults reported

using it more often than older adults ($BF_{incl} = 9.20$). There was also strong evidence in favor of the interaction between articulatory suppression and age ($BF_{incl} = 29.07$). Bayesian independent t-tests conducted separately for each articulatory suppression condition with age as a between-subjects factor indicated that younger adults reported using the phonological strategy more often than older adults in the no-articulatory suppression condition ($BF_{10} = 20.48$). The analysis could not be conducted in the articulatory suppression condition as none of the older adults reported using the phonological strategy in this condition. Younger adults also reported very little use of this strategy in this condition (see Table 5). Interestingly, these results suggest that although older adults were as affected as younger adults by reduced rehearsal opportunities for their recall accuracy, they may use articulatory rehearsal less frequently. For the semantic strategy, the additive model including main effects of articulatory suppression and age was the best ($BF_{10} = 1.77 \times 10^4$). As expected, participants reported using the semantic strategy more often in the articulatory suppression condition than in no-articulatory suppression condition ($BF_{incl} = 1.12 \times 10^4$). There was weak evidence for an effect of age ($BF_{incl} = 1.82$). For the phono-semantic strategy, the model that included only the main effect of articulatory suppression was the best ($BF_{10} = 11.2$), with participants reporting more frequent use of this strategy in the no articulatory suppression condition. For the other-strategy or no-strategy reports, the best model included only the effect of articulatory suppression, but the evidence was weak ($BF_{10} = 1.31$; $BF_{10} = 1.05$, respectively).

Table 5.

Percentage of reported strategy use as a function of age group and articulatory suppression condition in Experiment 1.

Age	Articulatory suppression	Strategy type				
		Phonological	Semantic	Phono-semantic	Other	None
YA	Suppression	2.86 (16.9)	62.9 (49)	-	11.4 (32.3)	22.9 (42.6)

	No suppression	60 (49.7)	22.9 (42.6)	5.71 (23.6)	2.86 (16.9)	8.57 (28.4)
	Suppression	-	80 (40.8)	-	4 (20)	16 (37.4)
OA	No suppression	20 (40.8)	48 (51)	20 (40.8)	-	12 (33.2)

Note. Standard deviations are in brackets. YA is for younger adults and OA is for older adults.

The percentage of reported strategy use corresponds to the percentage of participants in each group (younger or older adults) who reported using each strategy in each condition (articulatory suppression or no suppression) out of the total number of participants in each group.

Recall Accuracy as a function of Strategy Use. Finally, we conducted several Bayesian ANOVAs to examine the effect of reported strategy type on the percentage of correct recall, semantic, and non-semantic errors as a function of articulatory suppression condition and age. There was no substantial effect of reported strategy type on correct recall, regardless of condition and age ($BF_{10s} < 1.22$).

Discussion

Although semantic errors were the most common, older adults did not make substantially more of them than younger adults. However, consistent with the principle of decreasing representational specificity with age (Greene & Naveh-Benjamin, 2023), older adults had poorer correct recall performance than younger adults and reported using fewer specific representations than younger adults when recalling studied words. Interestingly, reducing opportunities to use articulatory rehearsal decreased correct recall performance and specifically increased semantic errors for both younger and older adults. This manipulation also had the effect of reducing the retrieval of specific representations associated with correct recall, which is consistent with previous findings showing reduced retrieval of verbatim representations under articulatory suppression in young adults (Abadie & Camos, 2019), and the present study is the first to show the same effect in older adults. Regarding the question of the use of articulatory rehearsal during aging, the results of the present study suggest that

older adults, like younger adults, benefit from having more opportunities to use rehearsal to maintain words, both in terms of their correct recall performance and the reduction of false memories. Thus, a deficit in the use of articulatory rehearsal with age did not appear to account for the decline in correct recall performance observed in older adults in this experiment, which is consistent with studies showing no effect of age on the use of this mechanism (e.g., Loaiza & McCabe, 2013; Heiring et al., 2019). However, results on self-reported strategies suggest that, conversely, older adults were less likely than younger adults to use the articulatory rehearsal strategy (i.e., phonological strategy) when given the opportunity to do so. These findings are consistent with those of Loaiza and McCabe (2013), who showed less use of this strategy among older adults, although this did not account for age-related differences in correct recall.

The latter result was surprising, however, given that both younger and older adults' recall performance was better when they had more opportunities to use rehearsal. This may suggest that older adults were less aware of the use of articulatory rehearsal than younger adults. However, the assessment of the strategies used in this experiment was imprecise. Participants reported them at the end of the experiment and may have forgotten or confused the strategies they used in each condition. It is also possible that they used different strategies on each trial, which could not be assessed by the measure used. We therefore conducted a second experiment in which we measured strategy use more precisely on a trial-by-trial basis. Moreover, participants' recall performance was still high (>80%) in the articulatory suppression condition, suggesting that they were able to maintain the majority of words over the retention interval despite articulatory suppression and the attentional demand of the concurrent task. In the second experiment, we increased the number of words to be maintained as well as the attentional demand of the concurrent task in order to increase our chances of obtaining age-related differences in the use of articulatory rehearsal and in the

occurrence of semantic errors. It is indeed possible that although older adults benefit from opportunities to use rehearsal, they use it less frequently than younger adults, as they reported, but that we didn't detect this on recall accuracy in this first experiment because the use of different strategies, such as attentional strategies was possible regardless of the articulatory suppression condition.

Experiment 2

The method of the second experiment was similar to that of Experiment 1, except that the attentional demands of the concurrent task and the number of words to be maintained were increased. In addition, the type of strategy used was assessed on each trial, allowing a more precise examination of the relation between the type of strategy reported and recall accuracy.

Method

Participants

Ninety-two participants, 45 younger adults and 47 older adults were recruited on a voluntary basis from Aix-Marseille University and the surrounding community. All participants were native French speakers, self-reported to be in good health, had normal or corrected-to-normal hearing and vision, and had not participated in Experiment 1. Data from two older adults were omitted because they scored below the standard cut-off on the MoCA. The final sample consisted of 45 younger adults aged 18-30 and 45 older adults aged 60-76 (see Table 1). There was weak evidence for a difference in the proportion of women and years of education between both age groups ($BF_{10} = 1.19$, $BF_{10} = 1.79$, respectively).

Materials

Word Lists. To ensure that the effects obtained in the first experiment were not contingent on the word lists used, 20 semantically related lists were selected anew from the original DRM lists (Roediger & McDermott, 1995; Roediger et al., 2001). The first five associates of the 40 DRM lists were translated into French by a bilingual speaker. These lists

were then rated by 40 younger adults who did not participate in the experiment. For each list, participants were asked to indicate how semantically related the five words of each list were to each other on a scale from 1 weakly related to 7 strongly related. They were then asked to indicate the common theme of each list. We selected the 20 lists for which the largest number of participants produced the theme (93.1%, $SD = 7.6$) and which had the highest semantic relatedness score ($M = 6.52$, $SD = 0.53$). We also made sure that the selected lists contained only neutral words of 1 to 2 syllables. The 20 lists were then separated into two groups of 10 lists similar in terms of semantic relatedness ($BF_{10} = .42$) and number of participants who produced the theme ($BF_{10} = .40$).

Subjective Experience. In addition to the three judgments used in Experiment 1, a fourth judgment was added to account for the possibility that participants might occasionally recall semantically related words that were not presented knowingly (i.e., a “related” response). Participants were instructed to utilize the “related” response when they recalled a word they believed they had not previously encountered in the list of words presented, but which was related in meaning to one or more of the words to be remembered.

Procedure

This experiment was programmed using the experimental platform Labvanced (Finger et al., 2017). All data were collected and stored both on a laboratory computer and on the Labvanced servers in Falkenstein, Germany. These servers are located in data centers with ISO/IEC 27001 certification and are operated by Hetzner GmbH. Labvanced data policy complies with the latest EU data privacy regulations (General Data Protection Regulation). Participants were tested in person in a quiet room in the presence of the experimenter.

The procedure was similar to that of Experiment 1, except for three changes. The task was made more difficult to emphasize the differences observed in Experiment 1. First, each list included 5 semantically related words. Second, we increased the attentional demand of

the concurrent task. In Experiment 1, we had set the ISI between each spatial fit item to 500 ms, which left enough time between the processing of two spatial fit items for participants to rethink the words to be maintained. We decided to reduce this ISI to 200 ms in Experiment 2. We, then, conducted a pilot study to determine the mean processing time of a spatial fit item in a spatial fit task similar to Experiment 1 as a function of participants' age. The mean processing time for this type of item was 1169 ms ($SD = 181$) for older adults ($n = 26$) and 738 ms ($SD = 60.8$) for younger adults ($n = 21$). Based on these mean processing times, we adjusted the number of items in the spatial fit task and their presentation time so that the total task time and its attentional cost (Barrouillet et al., 2007) were equivalent between younger and older adults. Younger adults had to judge six spatial fit items presented for 920 ms each followed by a 200 ms ISI (i.e., total time of the concurrent task: 6720 ms), while older adults had to judge four spatial adaptation items presented for 1460 ms each followed by a 200 ms ISI (i.e., total time of the concurrent task: 6640 ms). Finally, to get a clearer indication of which maintenance strategies were used and when, participants were asked about their strategies at the end of each trial. They were asked to indicate a) which maintenance strategy (or strategies) they thought they had used and b) when, between encoding, the retention interval (i.e., when performing the concurrent task), or recall, they thought they had used it.

Results

Concurrent Task Accuracy

The null model was the best indicating that neither age group nor articulatory suppression condition had any impact on performance on the concurrent task. The mean performance of younger ($M = 84.12$, $SD = 10.68$) and older adults ($M = 83.50$, $SD = 16.77$) was high, indicating that all participants performed the task correctly.

Recall Accuracy

As in Experiment 1, two independent and trained raters classified the responses to the recall test. Interrater agreement was high before discussion among raters (unweighted $\kappa = 0.89$) and full interrater agreement was obtained after discussion. Table 6 shows the percentage of each type of response as a function of age group and articulatory suppression.

Correct Recall. As in Experiment 1, the additive model including main effects of articulatory suppression and age was the best ($BF_{10} = 1.34 \times 10^{26}$). As predicted, correct recall performance was reduced in the articulatory suppression condition compared to the no articulatory suppression condition ($BF_{incl} = 4.69 \times 10^{23}$). In addition, younger adults had better correct recall performance than older adults ($BF_{incl} = 528$). Finally, the analysis of effects provided substantial evidence against an interaction between age and articulatory suppression ($BF_{incl} = .21$), again suggesting that younger and older adults benefit from more opportunities to use articulatory rehearsal.

Recall Errors. As in Experiment 1, because the proportion of each type of non-semantic error (i.e., phonological errors, intrusions and other errors) was small, we aggregated them for the following analyses. The model that included the main effects of articulatory suppression, error type and age, as well as the interactions between articulatory suppression and error type and between error type and age, was the best ($BF_{10} = 2.90 \times 10^{72}$). We do not re-describe here the main effects of articulatory suppression and age on recall errors, which are the counterparts of their effects on correct recall. As in Experiment 1, semantic errors were more frequent than non-semantic errors ($BF_{incl} = 2.86 \times 10^{28}$) and there was decisive evidence for the interaction between articulatory suppression and error type ($BF_{incl} = 6.71 \times 10^{24}$). Paired-sample Bayesian t-tests conducted separately for each error type with articulatory suppression as a within-subjects factor, showed that semantic errors were more frequent in the articulatory suppression condition than in the no articulatory suppression condition ($BF_{10} = 1.48 \times 10^{24}$), while there was weak evidence for an effect of articulatory

suppression on non-semantic errors ($BF_{10} = .75$). Interestingly, there was also strong evidence for the interaction between error type and age ($BF_{incl} = 41.4$). Independent samples Bayesian t-tests conducted separately for each error type with age as a between-subjects factor provided decisive evidence that older adults made more semantic errors than younger adults ($BF_{10} = 261.07$), while there was weak evidence against an effect of age on non-semantic errors ($BF_{10} = .56$). These results replicate the increase in semantic errors with age observed in the classic DRM task (e.g., Chang & Brainerd, 2021). Finally, as in Experiment 1, there was substantial evidence against the interaction between articulatory suppression, error type, and age ($BF_{incl} = .33$), showing that both younger and older adults made more semantic errors in the articulatory suppression condition.

Table 6.

Percentage of correct recall and recall errors (semantic errors, phonological errors, intrusions and other errors) as a function of age group and articulatory suppression condition in Experiment 2.

Age group	Articulatory suppression	Correct Recall	Semantic errors	Phonological errors	Intrusion errors	Other errors
Younger adults	Suppression	81.3 (7.20)	16.9 (7.28)	.04 (.30)	.58 (1.18)	1.11 (1.73)
	No suppression	91.7 (5.70)	7.5 (5.47)	.18 (.72)	.44 (1.20)	.22 (.64)
Older adults	Suppression	75.3 (8.53)	22.6 (7.81)	.13 (.50)	.93 (1.84)	1.07 (1.79)
	No suppression	85.5 (7.96)	12.9 (7.19)	.18 (.58)	.53 (1.08)	.93 (2.43)

Note. Standard deviations are in brackets. The percentage of each type of response corresponds to the average number of responses of each type out of the total number of words to be recalled. Participants could also recall the same word more than once during a trial.

Correct and incorrect repetitions of the same word were not counted.

Subjective Experience. As in Experiment 1, we performed the same analyses as above for correct recall and recall errors including subjective experience as a within-subjects factor. Table 7 shows the percentage of each type of subjective judgment for correct recall, semantic

and non-semantic errors as a function of age group and articulatory suppression. The main results pertaining to the hypotheses are summarized below. Additional analyses are available at the OSF project [<https://doi.org/10.17605/OSF.IO/EJF52>].

For correct recall, when judgment type (studied vs. studied or related vs. related vs. guess) was included in the analysis, the main effect of judgment type and the interactions between articulatory suppression and judgment type and between judgment type and age were added to the model ($BF_{10} = \infty$). As in Experiment 1, correct recall was more often associated with studied judgment ($BF_{incl} = 5.94 \times 10^{233}$) and studied judgments were more frequent in no articulatory suppression condition than in the articulatory suppression condition ($BF_{incl} = 2.78 \times 10^{74}$) and in younger than in older adults ($BF_{incl} = 6553$).

Semantic errors were more often associated with related judgments ($BF_{incl} = 1.06 \times 10^{56}$) whereas non semantic errors were more often associated with guess judgments ($BF_{10} = 5391$).

Table 7.

Percentage of each type of subjective judgment (studied vs. studied or related vs. related vs. guess) associated with correct recall, semantic and non-semantic errors as a function of age group and articulatory suppression condition in Experiment 2.

		Subjective judgment					
	Age group	Articulatory suppression	Studied	Studied or related	Related	Guess	
Correct recall	YA	Suppression	76.2 (9.27)	3.38 (3.04)	1.51 (2.30)	.27 (1.01)	
		No suppression	88.80 (7.90)	2.31 (2.86)	.44 (1.03)	.12 (.50)	
	OA	Suppression	70.2 (11.08)	2.36 (2.64)	2.67 (3.16)	.08 (.42)	
		No suppression	82.22 (9.33)	1.87 (2.27)	1.16 (1.78)	.22 (.77)	
	Semantic error	YA	Suppression	2.27 (2.61)	2.62 (2.82)	11.4 (6.89)	.67 (1.41)
			No suppression	.80 (1.93)	1.47 (1.78)	5.02 (3.88)	.18 (.58)

	OA	Suppression	3.51 (3.17)	2.22 (2.34)	15.3 (7.06)	1.52 (2.99)
		No suppression	1.78 (2.14)	1.20 (2.11)	8.80 (6.33)	1.11 (2.40)
Non-semantic error	YA	Suppression	.27 (.69)	.13 (.50)	.40 (1.10)	.93 (1.51)
		No suppression	.27 (.69)	.13 (.66)	.18 (.72)	.26 (.81)
	OA	Suppression	.40 (.91)	0	.76 (1.72)	.97 (1.94)
		No suppression	.44 (.94)	0	.27 (.81)	.93 (2.72)

Note. Standard deviations are in brackets. YA is for younger adults and OA is for older adults.

The percentage of each type of subjective judgment corresponds to the average number of responses of each type of judgment for a given response type (correct recall, semantic errors or non-semantic errors) out of the total number of words to be recalled. Participants could also recall the same word more than once during a trial. Correct and incorrect repetitions of the same word were not counted.

Strategy Reports

Reported Strategy Use. Participants reported the strategy(s) they used per trial and per moment (encoding, retention interval, and retrieval) during the trial. Strategies were recoded according to the same classification as in Experiment 1. We distinguished between the use of phonological, semantic, phono-semantic, other and no strategy. Interrater agreement was high before discussion between raters (unweighted $\kappa = .88$) and full interrater agreement was achieved after discussion. For the sake of clarity, we have only reported analyses on strategies used during the retention interval, which reflect strategies for maintaining information in WM. Detailed analyses on strategies reported as a function of each moment are available at the OSF project [<https://doi.org/10.17605/OSF.IO/EJF52>]. Table 8 shows the percentage use of each type of strategy used during the retention interval as a function of age group and articulatory suppression condition.

Bayesian analyses were conducted to examine the effects of age and articulatory suppression on strategy reports, including strategy type as a within-subjects factor. For strategies reported during the retention interval, the full model was the best ($BF_{10} = 7.95 \times 10^{125}$). There was decisive evidence for the main effect of strategy type ($BF_{incl} = 2.77 \times 10^{82}$). Post-hoc comparisons showed that participants reported using no strategy during the retention interval more often than they reported using any of the four strategies ($BF_{10s, U} > 1.99 \times 10^{15}$). Among the strategies used, the phonological strategy was reported more frequently than the other three ($BF_{10s, U} > 2.08 \times 10^6$). The analysis of effects provided strong evidence against the main effects of age and articulatory suppression condition ($BF_{incls} < .09$). However, there was decisive evidence for the three-way interaction between age, articulatory suppression condition and strategy type ($BF_{incl} = 7.76 \times 10^5$). To decompose this interaction, Bayesian ANOVAs with articulatory suppression condition and age group were conducted for each strategy separately.

For the phonological strategy, the full model was the best ($BF_{10} = 3.20 \times 10^9$). As expected, the phonological strategy was reported more often in the condition without articulatory suppression than in the condition with articulatory suppression ($BF_{incl} = 4.79 \times 10^6$), and younger adults reported using it more often than older adults ($BF_{incl} = 57.3$). There was strong evidence for an interaction between the two factors ($BF_{incl} = 15.6$). Interestingly, independent-samples Bayesian t-tests provided strong evidence for the effect of age in the no-articulatory suppression condition ($BF_{10} = 130$), while there was weak evidence against the effect of age in the articulatory suppression condition ($BF_{10} = .93$), suggesting that older adults were less likely than younger adults to spontaneously use the rehearsal strategy to maintain the words when given the opportunity.

For semantic, phono-semantic, and other strategies, there was no substantial evidence for an effect of articulatory suppression condition and age group, i.e., no model was

substantially preferred over the null model ($BF_{10s} < 1.3$). For no strategy, the full model was the best ($BF_{10} = 1.63 \times 10^7$). Participants reported using no strategy more often in the articulatory suppression condition than in the no articulatory suppression condition ($BF_{incl} = 1.17 \times 10^6$). In addition, older adults reported using no strategy more often than younger adults ($BF_{incl} = 25.5$). There was also strong evidence for an interaction between the two factors ($BF_{incl} = 11.3$). Independent-samples Bayesian t-tests provided evidence for the effect of age in the no articulatory suppression condition ($BF_{10} = 27.7$), while there was weak evidence against the effect of age in the articulatory suppression condition ($BF_{10} = .46$).

Table 8.

Percentage of reported strategy use during the retention interval as a function of age group and articulatory suppression condition in Experiment 2.

Age group	Articulatory suppression	Strategy type				
		Phonological	Semantic	Phono-semantic	Other	None
YA	Suppression	13.6 (24.8)	.89 (2.88)	.22 (1.49)	5.11 (15.2)	80.2 (30.6)
	No suppression	48.9 (42.2)	.67 (2.52)	.89 (4.68)	3.55 (12.5)	46 (42.3)
OA	Suppression	5.33 (17.5)	3.11 (10.2)	-	3.56 (14)	88.0 (25.9)
	No suppression	18.5 (30.8)	4.22 (11.2)	-	4.22 (10.3)	73.1 (33.3)

Note. Standard deviations are in brackets. YA is for younger adults and OA is for older adults.

The percentage of reported strategy use corresponds to the percentage of trials in which a participant reported using a type of strategy out of the total number of trials in a given condition.

Recall Accuracy as a function of Strategy Use. To better understand the relation between reported strategies and recall accuracy, having data on the strategies used per trial in this experiment allowed us to first examine whether there were correlations between the percentage of each type of strategy reported and the percentage of correct recall, semantic, and non-semantic errors. Here again, we focused on strategies used during the retention

interval, which reflect strategies for maintaining information in WM. For younger adults, Bayesian correlation analyses provided substantial evidence for a positive correlation between percentage use of the phonological strategy and percentage correct recall ($r = .44$, $BF_{10} = 14.4$), and a negative correlation between percentage use of this strategy and semantic errors in the no articulatory suppression condition ($r = -.38$, $BF_{10} = 4.67$). For older adults, the analyses also provided decisive evidence for the same correlations between phonological strategy and correct recall ($r = .60$, $BF_{10} = 1611$) and semantic errors ($r = -.60$, $BF_{10} = 2129$) in the no articulatory suppression condition. The use of the other strategy was also negatively correlated with correct recall ($r = -.35$, $BF_{10} = 2.90$) and positively correlated with semantic errors in older adults ($r = .37$, $BF_{10} = 3.54$) in the no articulatory suppression condition. For both younger and older adults, there was no substantial evidence for other correlations between reported strategies and recall accuracy in the latter condition or in the articulatory suppression condition ($BF_{10s} < 1.62$).

These results suggest that the use of a phonological strategy during the retention interval in the no articulatory suppression condition could be beneficial for correct recall and reduce errors, especially semantic errors, in both younger and older adults. However, as we have shown in previous sections, older adults made fewer correct recalls, more semantic errors, and used the phonological strategy less often during the retention interval than younger adults. Therefore, in a second step, we conducted a mediation analysis to examine whether the use of the phonological strategy during the retention interval in the no articulatory suppression condition mediated the effect of age on correct recall and semantic errors. To perform a Bayesian mediation analysis, we followed the approach of Nuijten et al. (2014) and Liu et al. (2023). We computed the Bayes factors for the relation between age (independent variable) and the mediator, here the use of the phonological strategy (path α), and for the relation between the use of the phonological strategy and the outcome, here the percentage of correct

recall or semantic errors (path β), by performing Bayesian linear regressions. Then, we estimated the Bayes factor for the mediation effect (i.e., the indirect effect) using Liu et al.'s (2023) R tool. In addition, we computed standardized estimates for the different paths using the mediation analysis module of JASP (1000 bootstraps). The results of these analyses are summarized in Figure 2.

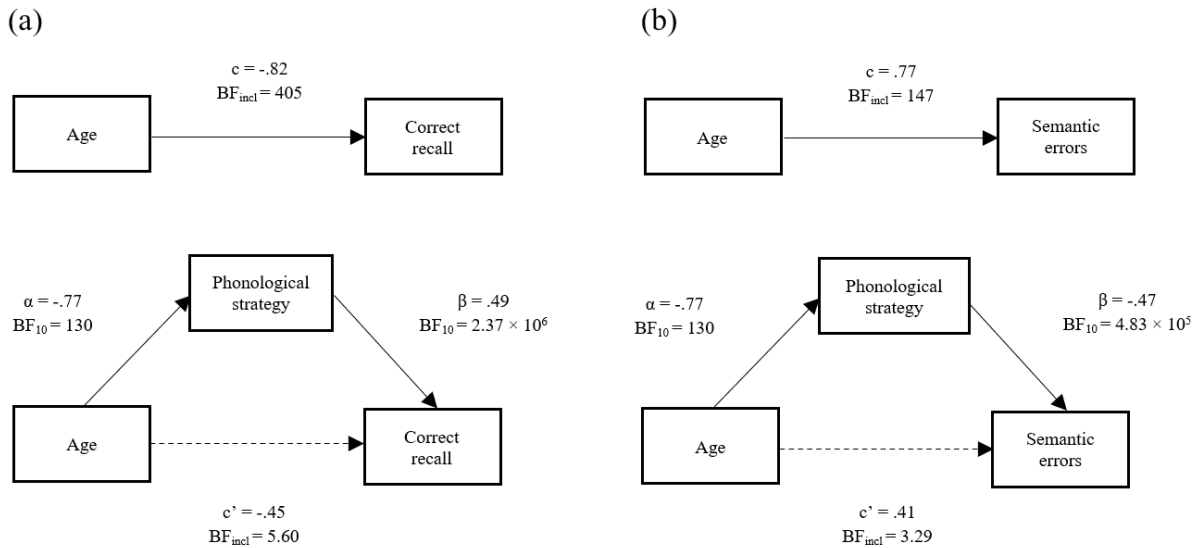
First, we examined whether phonological strategy use during the retention interval mediated the effect of age on correct recall. Phonological strategy use decreased with age ($\alpha = -.77$, $BF_{10} = 130$), and its use increased correct recall ($\beta = .49$, $BF_{10} = 2.37 \times 10^6$). There was decisive evidence for the indirect effect of age on correct recall through the use of the phonological strategy ($\alpha \times \beta = -.37$, $BF_{10} = 391$). Although, there was still evidence of an effect of age on correct recall when phonological strategy use was included in the model ($c' = -.45$, $BF_{incl} = 5.6$), this evidence was reduced compared to when the strategy use was not included ($c = -.82$, $BF_{incl} = 405$). This mediation analysis indicated that phonological strategy use partially mediated the effect of age on correct recall.

Second, we examined whether the use of the phonological strategy during the retention interval mediated the effect of age on semantic errors. The lower the use of the phonological strategy, the higher the semantic errors ($\beta = -.47$, $BF_{10} = 4.83 \times 10^5$). There was decisive evidence for the indirect effect of age on semantic errors through the use of the phonological strategy ($\alpha \times \beta = .36$, $BF_{10} = 391$). Although, there was still evidence of an effect of age on semantic errors when phonological strategy use was included in the model ($c' = .41$, $BF_{incl} = 3.29$), this evidence was reduced compared to when strategy use was not included ($c = .77$, $BF_{incl} = 147$). Thus, phonological strategy use partially mediated the effect of age on semantic errors. These mediation analyses showed the decrease in correct recall and the increase in semantic false memories with age, were due, in part, to older adults' reduced use

of the phonological maintenance strategy, i.e., the repetition of the words to be remembered, during the retention interval.

Figure 2.

Illustration of the mediating effect of reported phonological strategy use on the effect of (a) age on correct recall and (b) age on semantic errors.



Discussion

Consistent with the principle that the specificity of representations decreases with age (Greene & Naveh-Benjamin, 2023), as in Experiment 1, the correct recall performance of older adults was poorer than that of younger adults, and correct recall was associated with the retrieval of less specific representations in older adults. The frequency of semantic errors was greater in this experiment than in the first, due to the increased difficulty of the task, and they were especially more frequent in older adults than in younger ones. These errors were not produced randomly like the other types of errors, but were predominantly associated with "related" responses, suggesting that participants had some awareness of making a semantic error. Replicating the results of Experiment 1, articulatory suppression reduced correct recall and increased semantic errors in both younger and older adults, suggesting that both age groups benefit from opportunities to use rehearsal. Interestingly, however, a closer analysis of

the strategies used in each trial revealed that although older adults used the phonological strategy, they used it less frequently than younger adults over the retention interval. The implementation of this strategy, as shown elsewhere for young adults (e.g., Abadie & Camos, 2019), during this first phase of information retention proved to be essential not only for correct recall but also for preventing the occurrence of semantic errors, as indicated by the correlations between reported use of the strategy and correct recall and semantic errors. Finally, a mediation analysis showed that reduced use of articulatory rehearsal partially mediated the age-related decrease in correct recall and increase in semantic errors. Thus, the findings of this experiment suggest that older adults use articulatory rehearsal less frequently than younger adults, and that this age-related change may partially explain the increase in false memory observed with aging and, more generally, contribute to age-related differences in the maintenance of verbal information in WM.

General Discussion

The present study investigated the role of articulatory rehearsal in increasing false memory during aging. We conducted two experiments with younger and older adults in which we manipulated the availability of articulatory rehearsal during the maintenance of semantically related word lists in a Brown-Peterson task and asked participants to report the maintenance strategies they used either at the end of the experiment (Exp. 1) or after each trial (Exp. 2). Results showed that reducing opportunities to use rehearsal increased false memories and decreased correct recall in both age groups. Older adults also had poorer recall performance than younger adults (Exp. 1 and 2) and made more false memories (Exp. 2). These effects were partially mediated by the frequency of self-reported use of the rehearsal strategy during the retention interval (Exp. 2). These findings suggest that although rehearsal appears to be still used during aging, age-related changes in its frequency of use may account for differences in performance not only in correct recall but also in false memories between

younger and older adults in WM tasks. Below, we discuss in turn the effect of age on recall accuracy, the role of articulatory rehearsal in this effect, and conclude by emphasizing the importance of the articulatory rehearsal mechanism for maintaining verbal information in WM.

The effect of age on recall accuracy

The increase in false memories with age is a well-established phenomenon in long-term memory (e.g., Devitt & Schacter, 2016). This phenomenon has been explained by the decreasing specificity of representations with age (e.g., Greene & Naveh-Benjamin, 2023). Some studies suggest that executive and WM deficits may contribute to the loss of representational specificity with age (McCabe et al., 2010). The present study is the first to replicate the age-related increase in false memories in a WM task in which participants had to retain four or five words for a retention interval of a few seconds. In both experiments, older adults made about 5% more semantic recall errors, i.e. false memories, than younger adults. The fact that false memories can occur in this type of task (10.5% on average across conditions) suggests that semantic processing can take place in WM. Moreover, the results of the present study suggest that the use of semantic processing to maintain information in WM increases with age. Older adults had more false memories than younger adults, and they also reported using more semantic strategies than younger adults. Semantic retrieval in long-term memory is a process that is relatively unaffected by age, as evidenced by the relatively stable performance generally observed in older adults on tasks that require access to semantic representations, such as vocabulary (e.g., Verhaeghen, 2003). Thus, it may be that older adults rely more heavily on semantic processes to maintain information in WM due to a decline in the efficiency of other executive and/or attentional processes (e.g., Naveh-Benjamin & Cowan, 2023), leading them to make more short-term false memories than younger adults.

The role of articulatory rehearsal in the age-related increase in short-term false memories

Recent studies have shown that the use of articulatory rehearsal reduces the occurrence of false memories in WM tasks in young adults (e.g., Abadie & Camos, 2019; Abadie et al., 2023). In the present study, as in younger adults, reducing the opportunity to use articulatory rehearsal to maintain semantically related word lists increased false memory rates by 7-10% in older adults in both experiments. This manipulation also had the effect of reducing the rate of correct recall associated with retrieval of specific representations in both younger and older adults. These results underscore the importance of this mechanism for the short-term maintenance of precise, verbatim representations of encoded information and for counteracting the emergence of semantic errors. Consistently, other recent studies have also highlighted the importance of phonological processing for WM retrieval (Coane et al., 2024; McBride et al., 2019). These studies have shown higher levels of false memories after short delays for phonologically related lists than for semantic lists. Overall, these results suggest that short-term false memories reflect an increased reliance on semantic knowledge stored in long-term memory for the maintenance of information when the use of certain mechanisms specific to WM, such as articulatory rehearsal, is impaired. However, they do not rule out the possibility that WM mechanisms other than articulatory rehearsal may maintain or even contribute to the formation of semantic representations (e.g., Loaiza & Camos, 2018; Loaiza & Srokova, 2020).

The fact that older adults' recall performance is as affected by reduced opportunities to use rehearsal as younger adults suggests that the mechanism is relatively preserved from the effects of aging. This finding seems to contradict that of reported strategies. Older adults reported using articulatory rehearsal (i.e., the phonological strategy) less often than younger adults in the no-articulatory suppression condition, i.e., in which the use of rehearsal was not

impaired. However, in this condition, older adults recalled between 5% and 6% fewer words correctly and made between 3% and 5% more semantic errors than younger adults. The mediation analysis conducted in Experiment 2 showed that this difference in performance could be partially explained by a more frequent use of the rehearsal strategy during the retention interval in younger adults. Given the high attentional demand of the concurrent task that participants had to perform, rehearsal, which is a low attentional demand strategy (e.g., Camos & Barrouillet, 2014; Chen & Cowan), was probably most effective in the condition without articulatory suppression.

Numerous studies show that articulatory rehearsal does not maintain long-term traces (e.g., Greene, 1987). Some recent models of WM (Barrouillet & Camos, 2021; Barrouillet et al., 2021) propose that rehearsal restores sensory input through output planning processes that do not rely on long-term memory traces after the initial configuration of the articulatory program. According to this view, articulatory rehearsal would be a non-attentional mechanism that allows the reproduction of the articulatory form of verbal items. The decrease in the use of rehearsal in older adults may seem at odds with the age-related decline in attentional resources (Naveh-Benjamin & Cowan, 2023), because this latter decline should lead older adults to prefer attention-saving maintenance strategies such as rehearsal (e.g., Turley-Ames & Whitfield, 2003). It may be, as some studies suggest (e.g., Chevalère et al., 2020), that the effectiveness of this mechanism is compromised in older adults due to the reduced speed of articulation with aging. Moreover, age-related deficits also affect the implementation of executive functions such as inhibition, information updating, and attentional switching, which are essential for selecting the most appropriate maintenance strategy for a given task (e.g., Hasher & Zacks, 1988). Younger adults are able to change their maintenance strategy according to the characteristics of the items to be remembered (Belletier et al., 2023; Camos et al., 2011). For example, when words to be remembered share phonological features,

younger adults switch to an attention-based maintenance strategy instead of rehearsal to avoid phonological confusion (Camos et al., 2011). Several studies have shown that aging reduces the ability to select the more appropriate strategy in memory tasks (Dunlosky & Hertzog, 2001; Taconnat et al., 2009) and other cognitive domains (Lemaire et al., 2004; Hotzig & Lemaire, 2011).

In the present study, the rehearsal strategy was the most appropriate in the no articulatory suppression condition due to the high attentional demand of the concurrent task and the semantic associations between the words to be remembered. Indeed, rehearsal is a low-attentional demand strategy that allows the surface, articulatory form of verbal items to be maintained, thus preventing the occurrence of semantic errors. Results showed that a decrease in the use of this strategy contributes to age-related differences in the rates of correct recall and false memories. In addition, older adults reported using more semantic strategies. These strategies, such as semantic elaboration, are effective for long-term remembering of information (e.g., Bartsch et al., 2019), but not for preventing short-term false memories. Thus, older adults may have used semantic processing as well as their long-term memory knowledge to compensate for age-related executive and attentional deficits. This is consistent with the metaphor proposed by Naveh-Benjamin and Cowan (2023, p. 162) that "it is as if older adults are sitting on a three-legged stool, with one firm leg (knowledge), a second leg that can be made strong with reinforcement (practice at a task), and a third leg that is inevitably a little weaker and needs a brace (executive function and use of attention)". The findings of the present study therefore seem to support the idea that older adults have difficulties in using the most appropriate maintenance strategy, which would contribute to age-related differences in WM recall performance. Thus, both information processing speed and executive function are affected by aging, but future research is needed to determine more precisely whether and how this might lead to age-related changes in the use of WM strategies.

Concluding comments

The present study highlights the importance of articulatory rehearsal for maintaining specific short-term representations, thereby reducing the occurrence of false memories and promoting correct recall in WM tasks. It is the first to show that age-related changes in the use of articulatory rehearsal account in part for the increase in false memories during aging. More broadly, these changes may also partially explain differences in WM recall performance between young and older adults. These findings provide evidence for the effectiveness of articulatory rehearsal as a short-term maintenance strategy. Future research will need to determine the causes, such as reduced articulation speed or difficulties in strategic adaptation, of these age-related changes in the use of rehearsal.

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Data availability statement

Materials, data and additional analyses are available at the OSF project [<https://doi.org/10.17605/OSF.IO/EJF52>].

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