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## **Reducing Age Differences in the Retrieval of Verbatim and Gist Representations:**

### **Encoding Manipulations**

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### Abstract

Aging causes changes in episodic memory. While the ability to remember the general idea or gist of past episodes is relatively preserved from the effects of aging, the ability to remember the verbatim details of these episodes declines. The aim of the present study was to examine whether age-related differences in the quality of episodic representations could be reduced by manipulations of information encoding. Two experiments were conducted with younger adults ( $N_{Exp.1} = 32$ ,  $N_{Exp.2} = 31$ , 18-27 years old) and older adults ( $N_{Exp.1} = 31$ ,  $N_{Exp.2} = 30$ , 54-81 years old) in which either the retrieval of gist representations of studied items was facilitated by presenting items that could be grouped within the same category (Exp. 1) or the retrieval of verbatim details of studied items was facilitated by presenting the same items repeatedly (Exp. 2). Both manipulations proved effective in increasing retrieval of either gist or verbatim representations in a recognition task in younger and older adults. Increasing gist retrieval improved correct recognition performance for both younger and older adults, but also led the latter to make more recognition errors. Increasing verbatim retrieval improved correct recognition performance for both younger and older adults, and the gain was greater for older adults. These findings support the notion that age-related changes in episodic memory can be explained by changes in the specificity of representations and suggest that simple encoding manipulations could improve episodic memory in older adults.

**Keywords:** Encoding manipulations, Aging, Fuzzy-trace theory, Episodic memory

A change in the quality of episodic memory representations occurs during aging; episodic memories become less specific but retain the essence of past experiences (see Greene & Naveh-Benjamin, 2023, for a review). Several theories from psychology and cognitive neurosciences distinguished detailed or specific representations from less detailed and more general representations. Among these is the Fuzzy-trace theory (FTT), which is a theory of cognitive development that distinguishes between verbatim and gist representations. Verbatim traces represent the specific details of an episode whereas gist traces represent the semantic features and general meaning of the episode (Brainerd & Reyna, 2015). This theory posits that increasing age in adulthood is associated with a significant decline in verbatim memory and a less pronounced decline in gist memory (Brainerd et al., 2009). These assumptions are supported by numerous studies in a wide range of domains, from decision-making (e.g., Kim et al., 2005; see Reyna & Brainerd, 2011, for a review) to false memory research (e.g., Koutstaal & Schacter, 1997; Norman & Schacter, 1997; Tun et al., 1998, see Devitt & Schacter, 2016, for a review) to associative memory studies (e.g., Greene & Naveh-Benjamin, 2020, 2022a). All these studies converge on what a recent review of the literature considered to be a universal principle of cognitive aging, according to which “older adults’ episodic memories are representationally less specific/detailed than those of younger adults” (Greene & Naveh-Benjamin, 2023, p. 76).

The aim of the present study was to investigate whether age-related differences in the quality of episodic memory representations can be reduced by simple manipulations of material presentation. We used, for the first time, two very easy-to-implement manipulations - the presentation of information that can be grouped into categories (Exp. 1) and the repetition of the same information (Exp. 2) - to promote the retrieval of gist or verbatim representations in older adults. These two manipulations have previously been shown to enhance the retrieval of gist or verbatim representations in young adults (Brainerd et al., 1999; Stahl & Klauer,

2008), but their effect has never been tested in older adults. Answering this question has important theoretical and practical implications. From a theoretical perspective, demonstrating that manipulations favoring the retrieval of verbatim representations (Exp. 2) or allowing adequate task performance without relying on them (Exp. 1) attenuate age-related differences in episodic memory would establish a causal relationship between reduced verbatim retrieval and age-related differences in episodic memory. This would strongly support the principle of age-related changes in the specificity/detail of representations. From an applied perspective, such findings would suggest that simply changing the way information is presented could compensate for certain age-related deficits in episodic memory.

### **Age-related Differences in Episodic Memory Representations**

The FTT posits that age-related deficits in episodic memory reduce the retrieval of verbatim representations, while gist memory is relatively spared. According to the FTT, the sensitivity of verbatim traces to the accumulation of interference is a major feature of aging (e.g., Brainerd et al., 2009), while memory for the core meaning or gist of an episode is relatively preserved from the effects of healthy aging (e.g., Brainerd et al., 2011; 2013). These assumptions are supported by studies that apply a mathematical model to recall tasks to measure the development of three memory processes. Brainerd et al. (2009, Brainerd & Reyna, 2010) propose that in recall tasks, participants retrieve verbatim traces of the items to be remembered via a recollective retrieval operation and gist traces of these items are processed via a non-recollective retrieval operation, referred to as reconstruction. Familiarity, the third process, is conceived as a slave judgment operation of the reconstruction process, which is assumed to perform confidence checks. Re-analysing data sets from several studies in which older adults (70-80 years) performed standard recall tasks and comparing their performance to those of younger adults, Brainerd et al. (2015) reported that direct access, i.e., the recollective retrieval operation, declined markedly with age. Reconstruction also declined

with age but by much smaller amounts than direct access. The familiarity judgment, on the other hand, was unaffected by aging.

Other studies have examined the effect of aging on the representations that are retrieved via recollective and non-recollective processes in recognition tasks. Although a large number of studies from many different domains suggest that older adults have specific difficulty retrieving verbatim representations of past episodes (e.g., Castel, 2005; Flores et al., 2017; Gallo et al., 2019), few have attempted to empirically disentangle the respective contributions of verbatim and gist traces within a single task. Abadie et al. (2021) used the simplified version of the conjoint recognition (CR) paradigm and model (Brainerd et al., 1999, Stahl & Klauer, 2008) to estimate verbatim and gist memory retrieval in younger and older adults in a single recognition task. Participants studied a series of words, some of which were semantically related to each other and to a common theme. In the test phase, participants were presented with target probes (i.e., items from the study list), related distractors (i.e., items that had not been presented on the study list but are semantically related to a target item) and unrelated distractors (i.e., new items that were neither part of the study list nor were related to a target item) and were asked to classify each one as either a target probe, a related distractor or an unrelated distractor. Performance on the CR memory test is determined by the interplay of verbatim memory, gist memory and guessing processes. Results showed that the ability to retrieve verbatim traces of target items, which enables correct recognition of target or related probes, is significantly impaired by age. In contrast, gist retrieval was not affected by age. Thus, recognition of target and related probes was based more on gist memory retrieval in older adults than in younger adults. This greater reliance on gist memory led older adults to correctly identify a number of target probes, but also to make more memory errors, such as endorsing related probes as having been studied.

Other studies have used the CR paradigm to estimate verbatim and gist memory using associative memory tasks. Greene and Naveh-Benjamin (2020, 2022a) presented participants with face-scene pairs (e.g., an old man paired with a park scene). In the test phase, they have to discriminate between intact pairs (e.g., the old man with the same park), highly related distractors (e.g., the old man paired with a different park), less related distractors (e.g., the old man paired with a forest) and unrelated distractors (e.g., the old man paired with a bakery). Results showed that older adults could retrieve the gist of associations but were impaired in their ability to retrieve more specific representations of associations. As a result, older adults misidentified highly related distractors as intact pairs more often than younger adults. Age differences were smaller for less related distractors and absent for unrelated distractors. These different studies applying the CR recognition model to different memory tasks converge on the same conclusion: older adults have deficits, relative to younger adults, in retrieving the verbatim traces of items per se, but they can retrieve their semantic features or gist.

### **Can Age-related Differences in Episodic Memory Be Reduced?**

There have been several demonstrations that representations become less specific as we get older in adulthood. However, to verify that it is indeed the loss of specificity of representations with age that accounts for differences in episodic memory (i.e., in recognition or recall performance) between younger and older adults, we need to show that age-related differences in episodic memory can be attenuated by making it easier for older adults to extract verbatim details from episodes or by interfering with this ability in younger adults.

Studies on associative memory provided some evidence in this direction. For example, Castel (2005) showed that age-related differences in episodic memory can be reduced when prior knowledge can help older adults retrieve new associations. Participants were presented with grocery items paired with prices that were either realistic (e.g., 250 g butter for \$2.99) or unrealistic (e.g., a tub of ice cream for \$17.59). Results showed that, compared to younger

adults, older adults were equally able to remember item-price associations for realistic item-price pairs, but were impaired for unrealistic pairings. These findings showed that age-related associative memory deficits can be reduced when older adults could rely on preexisting knowledge (e.g., item prices in the real world). Other studies have shown similar effects when preexisting schematic support can be used to the advantage of older adults (e.g., Castel et al., 2013; Gallo et al., 2019)

There is also evidence that interfering with the ability to extract verbatim details from information during encoding reduces the retrieval of verbatim representations in younger adults, eliminating their advantage over older adults. In a study by Greene and Naveh-Benjamin (2022b), face-scene pairs were shown to younger adults for further testing. During the study phase, half of the participants simultaneously completed an auditory choice reaction time task, the so-called divided attention condition, while the other half, in the full attention condition, only had to study the face-scene pairs. During the test phase, participants were presented with intact pairs, related distractors, and unrelated distractors (i.e., recombined face-scene pairs). The simplified CR model was used to estimate the contributions of verbatim and gist memory to the recognition task. Participants in the divided attention condition exhibited lower estimates of verbatim retrieval for intact probes and gist retrieval for related distractors. Importantly, the estimates of verbatim and gist memory retrieval obtained in this study were compared with those obtained from older adults who performed a similar task in the study by Greene and Naveh-Benjamin (2020). Although verbatim memory for intact probes was lower for older adults than for younger adults in the full attention condition, the estimates of verbatim retrieval no longer differed between older adults and younger adults in the divided attention condition. Gist memory retrieval for related probes was also higher for older adults than for younger adults in the divided attention condition.

The results of these studies, which manipulated the ability of younger and older adults to form verbatim and gist representations, are congruent with the hypothesis that deficits in episodic memory during aging could be due to the difficulties older adults experience in retrieving verbatim representations as they age. On the one hand, manipulations that made the retrieval of verbatim details unnecessary for the task were able to attenuate or eliminate age-related differences in episodic memory for, for example, prices or the week's weather. On the other hand, manipulations that interfered with younger adults' ability to retrieve verbatim representations also attenuated or eliminated age-related differences in the remembering of specific details of item pairs.

### **The Present Study**

Two experiments were conducted to test whether other simple manipulations of information encoding could reduce age-related differences in episodic memory recognition performance. We used the simplified version of the CR paradigm to estimate verbatim and gist representations of younger and older adults within the same recognition task, without having to manipulate the instructions given to participants. We selected two manipulations that have been repeatedly shown to specifically impact gist or verbatim representations in young adults in the CR paradigm (e.g., Brainerd et al., 1999; Stahl & Klauer, 2008).

In Experiment 1, we manipulated the activation strength of gist memory to examine the effect of aging on recognition performance as a function of the ease of retrieving gist traces of the items studied. We manipulated the gist memory of a concept by presenting a single or multiple items related to that concept during the study phase. When a concept is repeatedly activated by the presentation of multiple items during the study phase, memory for its gist is enhanced (e.g., Brainerd et al., 1999; 2001). We used categorical lists composed of different exemplars belonging to the same category (e.g., "musical instrument" list included the words "piano, guitar, violin, saxophone and drums") and varied the number of items (one or four)

presented in the study phase from a given category. This manipulation has been shown to be effective in affecting gist memory parameters in young adults in both the original and simplified CR paradigm (Brainerd et al., 1999; Stahl & Klauer, 2008). Gist memory was predicted to be greater for categories for which more exemplars were presented. Previous studies have shown that gist memory is preserved from the effects of aging, while verbatim memory declines (e.g., Abadie et al., 2021; Brainerd et al., 2015; Greene & Naveh-Benjamin, 2020, 2022a). Therefore, we expected that younger adults would retrieve more verbatim memory than older adults. Finally, activating the gist by presenting several items belonging to the same category would be particularly beneficial for older adults' recognition performance. The effect of age on correct recognition should be reduced in this condition compared to the condition in which only one exemplar per category is presented.

The aim of Experiment 2 was to implement a manipulation to facilitate the extraction of verbatim representations from the study list. We manipulated the strength of verbatim representations by repeatedly presenting targets from the study list. Each target was presented either once or four times. Presenting an item multiple times increases the exposure time to its perceptual details (e.g., the letters of the word, the sound of the word, etc.). Repetition has been shown to be effective in increasing verbatim memory in young adults in both the original and simplified versions of the CR paradigm (Brainerd et al., 1999, Stahl & Klauer, 2008). We expected that verbatim memory would increase when targets were presented four times. The effect of age on correct recognition should be reduced in this condition compared to the condition in which items were presented once.

## **Experiment 1**

### **Method**

#### *Ethics and Sample Size*

All the experiments were conducted in accordance with the recommendations of the APA Ethics Code. Study procedures were approved by the Aix-Marseille University Institutional Review Board, and all participants gave written informed consent prior to participation.

Based on the effect size of the difference between age groups (Cohen's  $d = 0.79$ ) in a previous study using a similar method (Abadie et al., 2021), a power analysis indicated that 27 participants per age group would be needed to achieve 80% power (G\*Power, Faul et al., 2009). We decided to collect at least 30 participants per age group 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***

Thirty-two younger adults and 31 older adults were recruited from Aix-Marseille University and the surrounding community on a voluntary basis. They received no compensation for their participation. 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 & Patel, 2016) was administered to older adults to screen for signs of abnormal cognitive decline. Data from two older adults were omitted as they scored below the standard 26-point threshold on the MoCA ( $n = 1$ ; Nasreddine et al., 2005) or did not complete the second session ( $n = 1$ ). The final sample thus comprised 29 adults aged 54-81 ( $M = 67.2$ ,  $SD = 5.37$ ) and 32 younger adults aged 19-26 ( $M = 20.6$ ,  $SD = 1.83$ ). All older adults scored above the standard cut-off on the MoCA ( $M = 28$ ,  $SD = 1.59$ , range = 26-30). Demographic measures for the younger and older adult samples are presented in Table 1. The proportion of women was significantly higher in the younger adult group than in the older adult group,  $\chi^2(1) = 9.88$ ,  $p = .002$ , due to the fact

that the younger adults were recruited amongst undergraduate psychology students, where women are in the majority. There were no significant differences in the number of years of education between both age groups,  $U = 497$ ,  $p = .629$ . A Bayesian independent t-test with a default Cauchy prior provided anecdotal evidence for no difference between the two age groups,  $BF_{10} = 0.42$ .

**Table 1**

*Demographic statistics for younger and older adult samples.*

Experiment	Demographic measure	Young adults	Older adults
1	<i>n</i>	32	29
	<i>n</i> females (% of sample)	29 (91%)	16 (55%)
	Age <i>M</i> ( <i>SD</i> )	20.6 (1.83)	67.2 (5.48)
	YoE <i>M</i> ( <i>SD</i> )	13.6 (1.27)	14.4 (3.29)
2	<i>n</i>	28	30
	<i>n</i> females (% of sample)	25 (89%)	21 (70%)
	Age <i>M</i> ( <i>SD</i> )	19.6 (2.25)	70.9 (6.05)
	YoE <i>M</i> ( <i>SD</i> )	12.4 (0.99)	15.6 (2.91)

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

### **Materials**

First, we took the 30 categorical lists (e.g., lists composed of musical instruments) developed by Stahl and Klauer (2008) in German and translated the two exemplars of each category into French with the help of a French-German bilingual. We then generated a further 10 categorical lists and added words to each of them based on French categorical norms (Bonin et al., 2013), so that each categorical list eventually comprised eight exemplars. We selected the five words most associated with the category based on a pilot study (e.g., the “musical instrument” list included the words “piano, guitar, violin, saxophone, and drums”). Thirty-two young adult university students with French as their mother tongue participated in the pilot study on a voluntary basis. They were given the name of the category (e.g., “musical instrument”) and asked to indicate, for each of eight exemplars (e.g., “piano, guitar, violin, etc.”), the extent to which it was semantically associated with the category on a scale from 1

(weakly associated) to 8 (strongly associated). We selected the five words with the highest average score for each category. The 40 five-word categories selected had a mean association score between each word and the category name of 5.54 (range = 4.68-6.03,  $SD = 0.31$ ).

Gist activation was manipulated by varying how many words from each category were presented in the study list. In the weak gist activation condition, a category (e.g., "musical instrument") was represented by a single word (e.g., "guitar") that was the second-most strongly associated exemplar of the category. In the strong gist activation condition, a category (e.g., "fish") was represented by four words (e.g., "trout, hake, sardine, bream"). These were the second, third, fourth and fifth exemplars of the category. The first exemplar of each category, i.e., the one most strongly associated with the category ('salmon'), was not presented, as it served as a related distractor for the recognition test. The study list contained words from the 40 selected lists that were randomly divided into two halves, one for the weak gist condition and the other for the strong gist condition. There were two counterbalances; the lists used for the weak gist condition for half of the participants were used for the strong gist condition for the other half, and vice versa<sup>1</sup>. Each condition consisted of 20 lists, and a total of 100 words were used for the study phase.

To form the recognition test list, the 20 single-word and 20 four-word lists were randomly divided into 10 lists in which the second exemplars of each were used as target probes and 10 lists in which the first exemplars of each, not presented in the study list, were used as related distractors. There were two counterbalances; lists tested with a target probe for half of the participants were tested with a related distractors for the other half of the participants and vice versa. There were also 20 unrelated distractors, which were words randomly selected from other categories not presented in the study list and unrelated to the studied categories. A total of 60 words were presented during testing in random order. To avoid task results being

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<sup>1</sup> Several Bayesian ANOVAs with counterbalancing as a between-subjects factor on correct recognition responses have provided evidence against an effect of counterbalancing ( $BF_{10s} < .585$ )

contaminated by fatigue, the task was performed in two sessions. In each session, 50 words were presented during the study phase and 30 words were presented during the test.

### *Procedure*

Experiment 1 was presented on a laboratory computer using the E-Prime 3.0 software (Psychology Software Tools, Pittsburgh, PA). All participants completed the experiment face-to-face, alone with the experimenter, in a quiet place, either in a laboratory cubicle or in a study room in a campus library. There were two testing sessions in the study. In each session, the simplified CR procedure was used. The task was similar in both two sessions, with the exception of the words used. Of the 100 selected words, 50 were studied and tested in the first session and 50 in the second session. The two sessions were separated by a break of up to half a day to avoid excessive fatigue and interference between the two sessions for older adults. The break was shorter (e.g., 20-30 min) for the younger group, to avoid losing participants between the two sessions. Figure 1 illustrates a session of the experimental procedure.

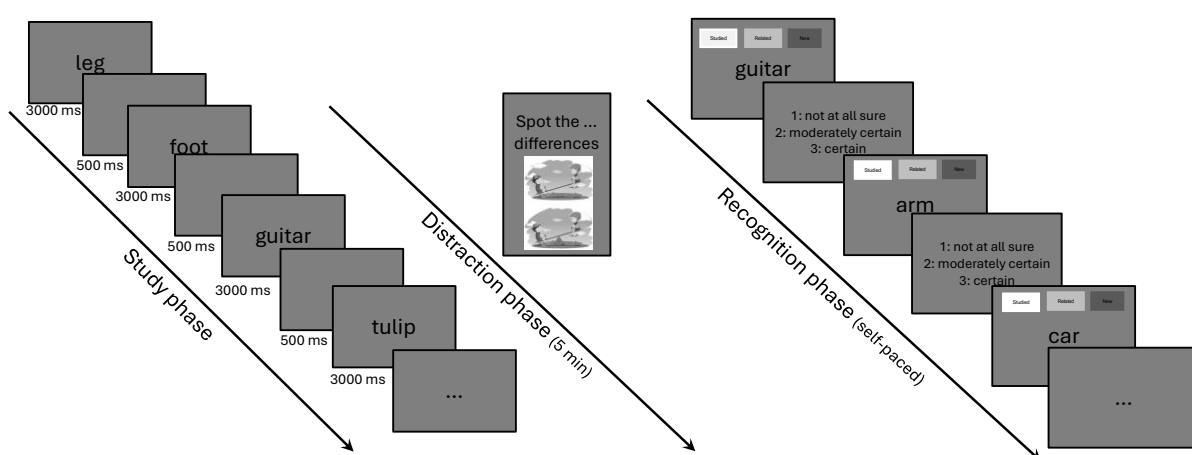
At the beginning of each session, participants were informed that they would be presented with a list of words to be remembered for a subsequent test. The words to be remembered from the strong and weak gist activation conditions were presented randomly and sequentially for 3000 ms followed by a 500 ms interstimulus interval (ISI). They were displayed in black letters on a medium-gray background. Each word was read aloud by the participants to ensure they encoded it correctly. After the study phase, participants performed a distraction task in which they had to spot differences between two images for a total duration of 5 min. Next, they were sequentially presented with the recognition list, consisting of one-third targets, one-third related distractors and one-third unrelated distractors. For each probe, they had to indicate whether it was identical to a word of the study list (i.e., a “target”), “related” to a word in the study list or “new” by pressing the corresponding key on an AZERTY keyboard (i.e., s, g, or l, respectively). The keys were identical for all participants. Finally, they

indicated their level of confidence in each of their responses on a 3-point scale, with 1 corresponding to “not at all confident”, 2 corresponding to “moderately confident”, and 3 corresponding to “confident”, by pressing the corresponding key (i.e., x, v, or n, respectively). The keys were the same for all participants.

A training phase preceded each experimental session. Participants completed the same memory task than in the experiment but with only six words. They were familiarized with the different probe types (i.e., target, related and unrelated distractors) of the memory test. To help them understand what a related distractor was, they were told that it was a word that had not been presented in the study list but that belonged to one of the studied word categories and were given an example. They could decide to restart the training phase as many times as they wished. At the end of the experiment, older adults completed the MoCA after a short break to prevent fatigue effects from contaminating test performance. Finally, all participants completed a demographic questionnaire (age, gender, education level) were thanked, debriefed, and dismissed.

### Figure 1

*Illustration of the experimental procedure.*



*Note.* In the study phase, words from the strong gist activation condition (e.g., trout, hake, ...) and the weak gist activation condition (guitar, tulip, ...) were randomly presented. In the distraction phase, participants completed as many boards of the difference game as possible

within the 5-minute period. In the recognition phase, 1/3 of the items were targets (e.g., guitar), 1/3 were related items (e.g., salmon), and 1/3 were new unrelated items (e.g., car).

## Results

### *Memory accuracy*

We first assessed whether facilitating the extraction of the gist from lists during encoding (i.e., the effect of gist activation) is beneficial for the accuracy of older adults' memory (i.e., proportion of correct responses for each probe type), using Bayesian ANOVAs. We focused on responses with high and moderate confidence ratings and did not analyze responses with low confidence ratings in order to limit the influence of random response bias on our analyses. The analyses were conducted using JASP version 0.18.1 (JASP Team, 2023). In the Bayesian statistical framework, the strength of evidence for or against each main effect and interaction can be assessed by a Bayes Factor (BF), where  $BF_{10}$  describes the Bayes factor in favor of the alternative hypothesis. Based on the classification proposed by van Doorn et al. (2021), a  $BF_{10}$  between 1 and 3 was considered as weak evidence for an effect, a  $BF_{10}$  between 3 and 10 as moderate evidence for an effect, a  $BF_{10}$  between 10 and 30 as strong evidence for an effect, and a  $BF_{10}$  greater than 30 as decisive evidence for an effect. The default JASP prior options, based on the recommendations of Rouder et al. (2012), were used for Bayesian ANOVAs. Table 2 shows the mean proportion of responses to the different probe types.

*Target probes.* A first Bayesian mixed-measures ANOVA was performed on high-confidence responses to the target probes with gist activation (weak vs. strong) and response type (target vs. related vs. unrelated) as within-subject factors and age group (younger vs. older adults) as a between-subject factor. First, we reported the best model, which is the model with the largest  $BF_{10}$ . Next, we analyzed the effects of each factor included in the best model (i.e., each main effect and interaction effect). The  $BF_{inclusion}$  ( $BF_{incl}$ ) value, which

indicates the likelihood of the data under models that included a given factor compared to all the models stripped of the factor, is reported for each factor tested in Table 3.

The best model included main effects of gist activation, response type and age group as well as interactions between gist activation and response type and response type and age group ( $BF_{10} = 1 \times 10^{49}$ ). However, it was only preferred by a factor of 1.6 over the second-best model, which also included the predicted interactions between gist activation and age group, as well as that between the three factors. While the analysis of effects provided moderate evidence against the interaction between gist activation and age, it provided moderate evidence for the interaction between the three factors (Table 3). Thus, we decomposed the latter interaction by conducting separate analyses by response type with gist activation and age group as factors. Regarding the correct identification of target probes, the best model included only the main effect of age group ( $BF_{10} = 216$ ), with younger adults correctly identifying targets with a high level of confidence more often than older adults. Regarding the identification of target probes as related distractors, the full model including the main effects of both factors and their interaction was the best ( $BF_{10} = 9.38 \times 10^{10}$ ). However, it was only preferred only by a factor of 1.93 over the second best model, which did not include the interaction between gist activation and age group. The analysis of effects provided weak evidence for the interaction ( $BF_{incl} = 1.85$ ). Target probes were misidentified as related distractors with high confidence more often in the strong than in the weak gist condition and in older than in younger adults. Regarding the identification of target probes as unrelated distractors, the full model was also the best ( $BF_{10} = 1.35 \times 10^5$ ). Older adults were still more prone to misidentify targets as unrelated distractors with high confidence, but paired samples t-tests indicated that there was decisive evidence for this effect only in the weak gist activation condition ( $BF_{10} = 75.2$ ;  $BF_{10} = 1.43$ , respectively).

A second mixed measures Bayesian ANOVA with the same three factors was performed on medium-confidence responses to the target probes. Medium confidence responses were less frequent than high confidence responses (Table 2). The best model included the main effects of all three factors ( $BF_{10} = 608$ ), but was only preferred by a factor of 1.02 over the second best model, which did not include the main effect of age. Moreover, the analysis of effects provided weak evidence for the effect of age ( $BF_{incl} = 1.01$ ). Medium confidence responses were more frequent in weak than strong gist conditions. Post-hoc comparisons showed that target responses were more frequent than related and unrelated responses ( $BF_{10, U} = 3.57$ ,  $BF_{10, U} = 2.02 \times 10^3$ , respectively).

*Related probes.* A new mixed measures Bayesian ANOVA with gist activation, response type and age group as factors was performed on high-confidence responses to related distractors. The best model included main effects of all three factors and interactions between gist activation and response type and between response type and age group ( $BF_{10} = 4.25 \times 10^{62}$ ). However, it was only preferred by a factor of 1.58 over the second-best model, which did not include the main effect of age group and the interaction between response type and age group. While the analysis of effects provided moderate evidence against the main effect of age group, there was moderate evidence for the interaction between response type and age group (Table 3). To decompose this interaction, independent Bayesian t-tests were performed separately for each response type with age as the grouping variable. There was evidence against the effect of age group for correct responses and false alarms ( $BF_{10} = 0.28$ ,  $BF_{10} = 0.52$ , respectively). By contrast, related distractors were more often identified as unrelated distractors with high confidence by older than by younger adults ( $BF_{10} = 5.9$ ). To decompose the interaction between gist activation and response type, paired Bayesian t-tests were performed separately for each response type with gist activation as a repeated-measure. Related distractors were more often correctly identified as related distractors ( $BF_{10} = 1.59 \times$

$10^{13}$ ) and falsely identified as targets ( $BF_{10} = 14$ ) in the strong gist activation condition than in the weak gist activation condition. By contrast, they were more often identified as unrelated distractors in the weak gist activation condition than in the strong gist activation condition ( $BF_{10} = 7.75 \times 10^5$ ).

Next, the same Bayesian analysis was performed on medium confidence responses to related distractors. The best model included the main effects of gist activation and response type, as well as the interaction between the two factors ( $BF_{10} = 1.79 \times 10^{14}$ ). Medium confidence unrelated responses were less frequent in the strong gist activation condition ( $BF_{10} = 4.18 \times 10^3$ ) and there was moderate evidence against an effect of gist activation for the two other response types ( $BF_{10s} < 0.32$ ).

*Unrelated probes.* A mixed measures Bayesian ANOVA with response type and age group as factors was then performed on high confidence responses to unrelated distractors. The best model included only the main effect of response type ( $BF_{10} = 5.26 \times 10^{36}$ ). It was preferred by only a factor of 1.88 over the second best model that also included the main effect of age group. However, the analysis of effects provided weak evidence against the main effect of age group (Table 3). Post-hoc comparisons indicated that unrelated distractors were more often identified as such than as targets ( $BF_{10, U} = 4.11 \times 10^{15}$ ) or related distractors ( $BF_{10, U} = 9.61 \times 10^{13}$ ). They were also more often classified as related distractors than as targets ( $BF_{10, U} = 385$ ).

Similar results were obtained with medium-confidence responses, for which the best model was also the one that only included the effect of response type ( $BF_{10} = 3.44 \times 10^{28}$ ).

## **Table 2**

*Proportions of different response types (target, related or unrelated) to different probe types (target, related or unrelated) as a function of associated confidence ratings (high, medium or*

low), gist activation (weak or strong) and age group (younger or older adults) in Experiment

1.

Probe type	Response	Confidence	Younger adults		Older adults	
			Weak activation	Strong activation	Weak activation	Strong activation
Target	Target	High	.68 [.603, .762]	.68 [.628, .741]	.46 [.366, .541]	.51 [.431, .590]
		Medium	.13 [.084, .172]	.07 [.044, .097]	.12 [.079, .162]	.07 [.045, .104]
		Low	.02 [.006, .038]	.03 [.009, .056]	.01 [.003, .028]	.00 [.000, .000]
	Related	High	.01 [.003, .025]	.12 [.078, .163]	.06 [.031, .103]	.24 [.183, .307]
		Medium	.03 [.016, .053]	.04 [.019, .066]	.10 [.055, .141]	.08 [.045, .110]
		Low	.02 [.006, .038]	.01 [.000, .019]	.03 [.007, .048]	.01 [.000, .021]
	Unrelated	High	.02 [.003, .028]	.00 [.000, .009]	.12 [.065, .172]	.03 [.010, .066]
		Medium	.04 [.022, .063]	.03 [.009, .047]	.07 [.041, .107]	.04 [.014, .066]
		Low	.05 [.028, .081]	.02 [.003, .038]	.04 [.010, .076]	.01 [.000, .031]
Related	Target	High	.01 [.003, .025]	.04 [.022, .072]	.01 [.000, .038]	.05 [.028, .079]
		Medium	.03 [.009, .044]	.05 [.034, .072]	.03 [.014, .045]	.02 [.003, .038]
		Low	.03 [.016, .056]	.01 [.000, .028]	.02 [.000, .041]	.00 [.000, .000]
	Related	High	.34 [.278, .409]	.61 [.528, .691]	.27 [.210, .317]	.57 [.503, .528]
		Medium	.11 [.066, .156]	.10 [.066, .141]	.12 [.076, .162]	.11 [.066, .148]
		Low	.03 [.019, .053]	.02 [.003, .028]	.05 [.024, .076]	.01 [.000, .021]
	Unrelated	High	.14 [.087, .194]	.03 [.006, .044]	.27 [.186, .355]	.09 [.041, .148]
		Medium	.23 [.178, .272]	.10 [.063, .138]	.16 [.110, .221]	.08 [.048, .121]
		Low	.08 [.053, .106]	.04 [.022, .069]	.08 [.031, .128]	.07 [.031, .117]
Unrelated	Target	High	.01 [0.002, .014]		.01 [0.000, .031]	
		Medium	.01 [0.003, .022]		.01 [0.002, .014]	
		Low	.02 [0.005, .031]		.01 [0.000, .014]	
	Related	High	.04 [0.023, .053]		.05 [0.026, .074]	
		Medium	.09 [0.059, .117]		.08 [0.043, .114]	
		Low	.01 [0.005, .025]		.03 [0.010, .045]	
	Unrelated	High	.38 [0.311, .374]		.48 [0.374, .584]	
		Medium	.36 [0.292, .425]		.28 [0.209, .343]	

Low                      .09 [.066, .123]                      .07 [.041, .103]

*Note.* 95% confidence intervals are in brackets.

**Table 3**

*BF<sub>inclusion</sub> value for each main effect and interaction as a function of gist activation (weak or strong), response type (target, related, or unrelated), and age group (younger or older adults) on high confidence response proportions for each probe type (target, related and unrelated) in Experiment 1.*

Effects	Probe type		
	Target	Related	Unrelated
Gist activation	7.77	9.79	--
Response type	$9.75 \times 10^{35}$	$9.13 \times 10^{29}$	$6.32 \times 10^{36}$
Age group	0.24	0.24	0.53
Gist activation $\times$ Response type	$4.35 \times 10^7$	$5.41 \times 10^{31}$	--
Gist activation $\times$ Age group	0.21	0.17	--
Response type $\times$ Age group	$1.29 \times 10^5$	6.19	0.49
Gist activation $\times$ Response type $\times$ Age group	3.03	0.46	--

### ***Verbatim and gist memory***

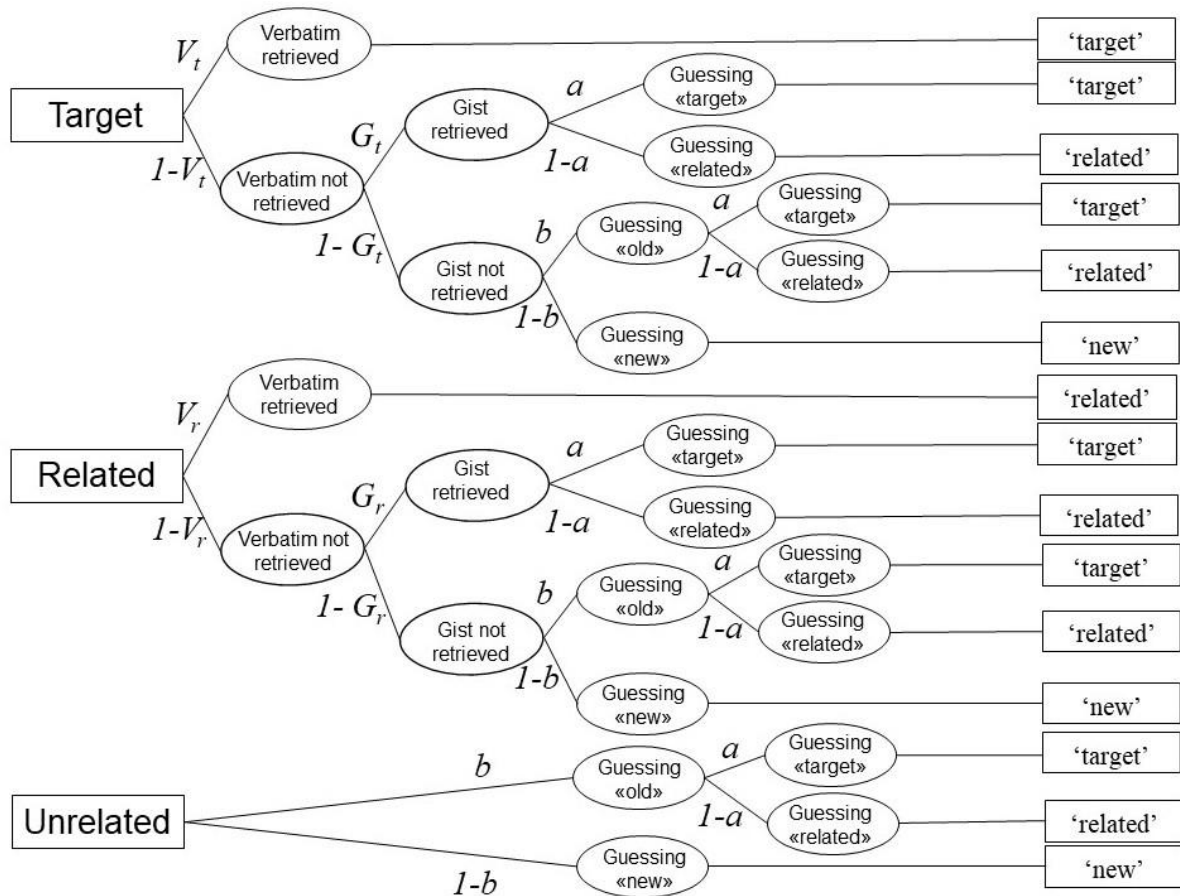
*The simplified conjoint recognition model.* The multinomial processing tree (MPT) model of the simplified CR paradigm (Stahl & Klauer, 2008) depicted in Figure 1 was used to compute parameter estimates for verbatim ( $V_t$ ) and gist memory for targets ( $G_t$ ), for verbatim ( $V_r$ ) and gist memory for related distractors ( $G_r$ ) and for guessing processes ( $a$  and  $b$ ). MPT models attempt to explain the processes (represented by the circles in Figure 2) by which participants give a response (represented by the boxes on the right in Figure 2) to a memory probe (represented by the boxes on the left in Figure 2). The probability of giving a response  $i$  to a probe  $j$  is estimated by summing the probabilities of each branch leading to that response.

The two parameters  $V$  represent the probability of retrieving a verbatim trace of a target when a target probe ( $V_t$ ) or a related distractor ( $V_r$ ) is presented during the recognition test.  $V_r$

is a recollection rejection process that allows the rejection of related distractors based on the retrieval of the verbatim trace of the corresponding target. The two parameters  $G$  correspond to the probability that, in the absence of verbatim memory, participants retrieve a gist trace of a target when a target probe ( $G_t$ ) or a related distractor ( $G_r$ ) is presented in the test. When participants retrieve a gist memory of a target item, they cannot remember whether the probe itself or a related word with the similar meaning was presented during the study phase. They must then guess whether the probe is a target (with probability  $a$ ) or a related distractor (with probability  $1 - a$ ). When neither verbatim nor gist memories are available, a participant can still guess that the probe's meaning is old with probability  $b$ . The decision between the target and related responses is again modelled by the parameter  $a$ . Otherwise, the participant guesses that the probe is new with the probability  $1 - b$ . Verbatim and gist traces do not intervene in responses to unrelated distractors, because these probes are not expected to trigger retrieval of verbatim or gist representations of the study phase. Therefore, responses to unrelated distractors are assumed to be based entirely on  $b$ .

**Figure 2**

*Multinomial processing tree for the simplified conjoint recognition paradigm based on Stahl and Klauer (2008)*



*Note.*  $V_t$  = probability of retrieving a verbatim trace of a target item when presenting a target probe;  $V_r$  = probability of retrieving a verbatim trace of a target item when presenting a related probe;  $G_t$  = probability of retrieving a gist trace of a target item when presenting a target probe;  $G_r$  = probability of retrieving a gist trace of a target item when presenting a related probe;  $b$  = probability of guessing that an item is either a target or a related probe;  $a$  = probability of guessing that an item is a target.

*Verbatim, gist and guessing parameter estimates.* Verbatim, gist and guessing group-level parameter estimates are given in Table 4. Analyses were conducted using a hierarchical latent-trait approach (Klauer, 2010). Models were estimated in the TreeBugs package in R (Heck et al., 2018; R Core Team, 2023). To ensure that the data fit the predictions of the simplified CR model, posterior predictive checks were computed, in which the posterior distributions of the model parameters were used to simulate 1000 new data sets. Then, the correspondence between posterior-predicted and observed means and covariances was

estimated via the  $T_1$  and  $T_2$  statistics (Klauer, 2010). A posterior-predictive p-value (PPP) was obtained for each statistic. PPP values larger than .05 reflect satisfactory model fit (Schmidt et al., 2022). The model was satisfactory in all cases, with  $PPP \geq .46$  for all  $T_1$  and  $T_2$  statistics.

**Table 4**

*Parameter estimates for verbatim and gist memory and guessing processes as a function of gist activation (weak or strong) and age group (younger or older adults) in Experiment 1.*

Parameter	Younger adults		Older adults	
	Weak gist	Strong gist	Weak gist	Strong gist
$V_t$	.82 [.754, .882]	.76 [.682, .837]	.57 [.454, .680]	.52 [.386, .647]
$V_r$	.17 [.009, .336]	.20 [.008, .531]	.13 [.005, .287]	.23 [.013, .476]
$G_t$	.26 [.041, .493]	.82 [.605, .975]	.35 [.074, .656]	.83 [.673, .951]
$G_r$	.30 [.070, .474]	.70 [.569, .826]	.26 [.064, .404]	.59 [.353, .768]
$b$	.15 [.101, .210]	.15 [.102, .208]	.16 [.111, .222]	.16 [.114, .213]
$a$	.17 [.044, .266]	.16 [.083, .250]	.11 [.038, .222]	.14 [.075, .232]

*Note.* Parameter estimates are group level means, and 95% Bayesian credible intervals are in brackets.

For each parameter, we computed a credibility interval of the difference between gist activation conditions and between age groups. The posterior samples obtained in the weak gist condition were subtracted from those obtained in the strong gist condition and those of the older adults were subtracted from those of the younger adults. The differences are shown in Table 5. Parameters for which the 95% credible interval (CI) of the difference estimates overlapped with 0 do not meaningfully differ (Smith & Batchelder, 2010). As expected, there were higher values of gist memory for target probes ( $G_t$ ) in the strong than in the weak gist condition in both age groups. Gist memory for related distractors ( $G_r$ ) was also increased in the strong gist condition in both age groups. Verbatim memory parameters ( $V_t$  and  $V_r$ ) were not affected by gist activation. As predicted, in both gist activation conditions, younger adults exhibited higher values of verbatim memory for targets ( $V_t$ ) but did not differ from older adults on gist parameters.

**Table 5**

*Differences scores between strong and weak gist conditions for younger and older adults, and between younger and older adults in weak and strong gist conditions in Experiment 1.*

Parameter	YA	OA	Weak gist	Strong gist
	Strong - Weak	Strong - Weak	YA - OA	YA - OA
$V_t$	-.06 [-.154, .029]	-.05 [-.202, .093]	<b>.26 [.124, .384]</b>	<b>.24 [.090, .392]</b>
$V_r$	.04 [-.244, .411]	.12 [-.164, .401]	.04 [-.195, .272]	-.03 [-.037, .374]
$G_t$	<b>.57 [.268, .850]</b>	<b>.46 [.126, .762]</b>	-.09 [-.462, .271]	-.00 [-.258, .218]
$G_r$	<b>.40 [.183, .656]</b>	<b>.32 [.034, .573]</b>	.04 [-.236, .301]	.11 [-.111, .378]
$b$	.00 [-.049, .052]	-.01 [-.059, .049]	-.01 [-.090, .067]	-.01 [-.082, .064]
$a$	-.01 [-.115, .098]	.03 [-.084, .139]	.06 [-.075, .180]	.02 [-.098, .132]

*Note.* YA = younger adult; OA = older adult. 95% credible intervals are in brackets. Bolded

difference scores exclude 0 from the 95% credible interval.

## Discussion

In this first experiment, we implemented a manipulation of information encoding, weakly or strongly activating the gist of a category by manipulating the number of items (one vs. four) belonging to a category. As predicted, this manipulation increased the retrieval of gist representations when identifying target and related items in both age groups. We also expected older adults to retrieve fewer verbatim representations than younger adults, which was the case in both weak and strong gist conditions. As also predicted, age had no effect on the retrieval of gist representations. Interestingly, this study showed for the first time a pattern of complementarity in the recognition of related distractors. Related distractors were both more frequently identified as related distractors and as targets in the strong than the weak gist condition. This pattern has been obtained repeatedly with the DRM paradigm and is thought to be due to the retrieval of gist representations (see Brainerd et al., 2021, 2022, for reviews). The present study is the first to obtain the same pattern with a different paradigm.

We expected that the manipulation of gist activation would be more beneficial for correct recognition for the older adults, who have more difficulty retrieving verbatim representations, than for the younger adults. The interaction between age group, gist activation and response type was obtained on responses to target probes. However, contrary to the predictions,

younger adults identified targets correctly more often than older adults, regardless of the gist activation condition. Older adults, in turn, identified target probes as related distractors more often than younger adults based on gist retrieval. The probability of responding "related" ( $r$ ) to target probes based on the retrieval of gist representations ( $G_t$ ) can be expressed as follows:

$$PG_{t(r)} = (1 - V_t) \times G_t \times (1 - a),$$

where  $V_t$  and  $G_t$  correspond to the probability of retrieving verbatim or gist representations, respectively, when presented with a target probe, and  $a$  corresponds to the probability of guessing that a probe is a target rather than a related probe. The probability of identifying a target probe as a related distractor based on gist retrieval was higher for older adults (13% and 34% in the weak and strong gist activation conditions, respectively) than for younger adults (4% and 17%). This age effect was greater in the strong gist activation condition than in the weak gist activation condition. For related probes, gist activation proved beneficial for both the older and the younger adults in correctly identifying these distractors as such. Correct responses based on gist retrieval increased for both younger (from 20% to 47%) and older (from 20% to 39%) adults in the strong gist activation condition compared to the weak activation condition.

These findings showed that facilitating the retrieval of gist representations improved correct recognition in both younger and older adults. However, this manipulation did not prove to be more beneficial for older adults, as gist activation also led them to make errors, such as misidentifying target probes as related distractors. Similar results were found by Abadie et al. (2021). In this study, gist activation was manipulated by presenting one or more items belonging to Deese-Roediger-McDermott lists (Roediger & McDermott, 1995). These lists consist of items that are strongly associated with an unrepresented critical theme that is used as a related distractor (e.g., "snow, ski, sled, glacier" are items that are strongly associated with the "mountain" theme). Results showed that strong gist activation led older

adults to correctly identify more target probes, but also to more frequently misidentify related distractors as targets based on gist retrieval.

Our next study focuses on verbatim memories, with the goal of examining whether an encoding manipulation that enhances the activation of these representations rather than the activation of gist representations might benefit older adults who have difficulty in retrieving precisely this type of memories.

## **Experiment 2**

In this study, the activation strength of verbatim representations was manipulated by varying the number of presentations of studied items. When the same item is presented multiple times, the exposure time to its perceptual details is multiplied. In young adults, this has been shown to increase the probability of forming verbatim representations of the item (e.g., Brainerd et al., 1999; Stahl & Klauer, 2008). We expected that target items presented multiple times would increase the probability of retrieving their verbatim representations in both younger and older adults. It is reasonable to assume that increasing exposure time to target items facilitates the formation of their verbatim representations, particularly for older adults who are slower than younger adults to encode information in memory (Salthouse, 1996). Younger adults, on the other hand, should be able to form verbatim representations even when target items were presented only once. Differences in recognition performance between younger and older adults should be reduced when target items were presented repeatedly.

### **Method**

#### ***Participants***

Thirty-one younger adults and 30 older adults were recruited from Aix-Marseille University and the surrounding community on a voluntary basis. They received no compensation for their participation. Participants were native French speakers. All

participants reported being in good health, with normal or corrected-to-normal hearing and vision. None of them participated in Experiment 1. All older adults scored above the standard cut-off on the MoCA ( $M = 28.3$ ,  $SD = 1.29$ , range = 26-30). Data from three younger adults were excluded because technical problems prevented them from completing the experiment ( $n = 1$ ) or because they failed to follow instructions ( $n = 2$ ). The final sample consisted of 28 younger adults aged 18-27 ( $M = 19.6$ ,  $SD = 2.25$ ) and 30 older adults aged 59-80 ( $M = 70.6$ ,  $SD = 5.67$ , see Table 1). As in Experiment 1, the proportion of women was significantly higher in the younger adult group than in the older adult group,  $\chi^2(1) = 5.33$ ,  $p = .021$ . The number of years of education of older adults was significantly larger than that of younger adults,  $U = 644$ ,  $p < .001$ .

### ***Materials and Procedure***

We selected 60 theme words and the word most strongly associated with each of them, based on French association norms (Bonin et al., 2013). The selected themes did not share any semantic associations with each other. The mean backward association strength, i.e., the probability of each word eliciting the theme word, between each theme and its most strongly associated word was .45 ( $SD = 0.21$ ). Forty of the selected associated words were used for the study phase. Theme words were not presented during the study phase because they served as related distractors in the recognition test.

To manipulate the number of presentations of the words studied, 20 of them were presented four times and the other 20 only once. The study list was counterbalanced so that words presented repeatedly for half the participants were presented once for the other half, and vice versa<sup>2</sup>.

The recognition list comprised 60 words. Twenty target probes were selected from studied words, 10 of which were presented four times and the other 10 presented only once. For

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<sup>2</sup> Several Bayesian ANOVAs with counterbalancing as a between-subjects factor on correct recognition responses have provided evidence against an effect of counterbalancing ( $BF_{10s} < .236$ ).

related distractors, 20 non-presented words that were semantically related (i.e., theme words) to 10 words presented four times and 10 words presented only once were used. Finally for unrelated distractors, we selected the associates of the remaining 20 out of 60 lists which were not used in the study phase. The recognition list was counterbalanced so that themes for which study words were presented in the recognition test for half the participants were presented as related distractors for the other half, and vice versa.

Like Experiment 1, this experiment was programmed with E-prime 3, and participants completed it face-to-face with the experimenter in a quiet room. The procedure was in all respects similar to that of Experiment 1 (Figure 1), except that only one test session was required, and the words presented were different.

## **Results**

### *Memory accuracy*

As in the first experiment, Bayesian mixed-measures ANOVAs were performed separately for each probe type, with number of target presentations (1 or 4) and response type (target, related or unrelated) as within-subject factors and age group (younger or older adults) as a between-subject factor on responses associated with high and medium confidence ratings. Table 6 shows the mean proportion of responses to the different probe types. The  $BF_{incl}$  value for each factor tested are reported in Table 7.

*Target probes.* For high-confidence responses, the best model included main effects of all three factors, as well as interactions between target presentation and response type, and between response type and age group ( $BF_{10} = 2.5 \times 10^{99}$ ). As predicted, paired Bayesian t-tests indicated that correct target identification with high confidence was more frequent when targets were presented four times during study rather than once ( $BF_{10} = 3.99 \times 10^{16}$ ). In contrast, misidentification of targets as related or unrelated distractors with high confidence was more frequent when targets were presented only once ( $BF_{10} = 20.5$ ,  $BF_{10} = 954$ ,

respectively). Independent Bayesian t-tests conducted to investigate the effect of age group on response type indicated that younger adults were better able to correctly identify target probes with high confidence than older adults ( $BF_{10} = 4.72$ ). As expected, it was especially true in the condition in which the targets were presented only once ( $BF_{10} = 4.10$ ). There was no evidence for an age group effect on misidentification of targets as related or unrelated distractors ( $BF_{10} = 0.42$ ,  $BF_{10} = 0.08$ , respectively).

For medium-confidence responses, the best model included the main effects of target presentation and response type, as well as the interaction between the two factors ( $BF_{10} = 1.02 \times 10^6$ ). Responses with medium confidence to target probes were less frequent for targets presented four times than for those presented once, which was particularly true for unrelated responses ( $BF_{10} = 4.51 \times 10^3$ ) and was also true for target and related responses, but the evidence was weaker ( $BF_{10} = 5.56$ ,  $BF_{10} = 14.6$ , respectively).

*Related probes.* For high confidence responses, the best model included main effects of target presentation and response type, and the interaction between target presentation and response type ( $BF_{10} = 4.95 \times 10^{26}$ ). However, it was only preferred by a factor of 1.85 over the second best model, which also included the main effect of age group and the interaction between response type and age group. The analysis of effects provided weak evidence against the main effect of age group and for the interaction between response type and age group (Table 7). Paired Bayesian t-tests performed to decompose the interaction between target presentation and response type showed that the correct identification of related probes with high confidence was more frequent when targets were presented four times rather than once ( $BF_{10} = 3.12 \times 10^5$ ). In contrast, their identification as unrelated distractors decreased when targets were presented four times ( $BF_{10} = 7.77 \times 10^3$ ). There was substantial evidence against an effect of target presentation on target responses ( $BF_{10} = 0.28$ ).

Similar results were obtained with medium-confidence responses, for which the best model was also the one that included main effects of target presentation and response type and the interaction between both factors ( $BF_{10} = 9.15 \times 10^5$ ).

*Unrelated probes.* For high confidence responses, the best model included main effects of response type and age group ( $BF_{10} = 5.57 \times 10^{22}$ ), but it was only preferred by a factor 1.08 over the second best model that did not include the age group effect. The analysis of effects provided weak evidence for the age group effect ( $BF_{10} = 1.06$ ). Post-hoc comparisons showed that high-confidence unrelated responses were more frequent than high-confidence related or target responses ( $BF_{10, U} = 1.31 \times 10^7$ ,  $BF_{10, U} = 3.62 \times 10^{12}$ , respectively).

For medium confidence responses, the best model also included the main effects of response type and age group ( $BF_{10} = 1.63 \times 10^{22}$ ), but it was only preferred by a factor of 1.18 over the model that also included the interaction between the two. However, the analysis of effects provided weak evidence for the main effect of age ( $BF_{incl} = 1.32$ ) and against the interaction ( $BF_{incl} = 0.85$ ).

**Table 6**

*Proportion of different response types (target, related or unrelated) to different probe types (target, related or unrelated) as a function of associated confidence ratings (high, medium or low), number of target presentations (1 or 4) and age group (younger or older adults) in Experiment 2.*

Probe type	Response	Confidence	Younger adults		Older adults	
			Target pres. 1	Target pres. 4	Target pres. 1	Target pres. 4
Target	Target	High	.64 [.578, .696]	.94 [.893, .970]	.50 [.407, .597]	.87 [.810, .923]
		Medium	.07 [.037, .104]	.01 [.000, .026]	.08 [.033, .137]	.05 [.017, .100]
		Low	.02 [.004, .030]	.01 [.000, .026]	.02 [.003, .030]	.00 [.000, .010]
	Related	High	.07 [.037, .104]	.02 [.004, .033]	.05 [.023, .083]	.02 [.003, .030]
		Medium	.04 [.015, .063]	.01 [.000, .033]	.05 [.027, .070]	.01 [.000, .020]

		Low	.01 [.000, .019]	.00 [.000, .000]	.00 [.000, .000]	.00 [.000, .000]
		High	.04 [.022, .070]	.00 [.000, .000]	.14 [.080, .200]	.02 [.003, .060]
	Unrelated	Medium	.11 [.070, .148]	.01 [.000, .019]	.10 [.060, .153]	.02 [.003, .060]
		Low	.02 [.004, .033]	.00 [.000, .011]	.04 [.010, .067]	.02 [.003, .047]
		High	.02 [.004, .030]	.03 [.004, .052]	.03 [.007, .053]	.04 [.013, .063]
	Target	Medium	.03 [.004, .067]	.02 [.000, .033]	.02 [.007, .033]	.02 [.003, .037]
		Low	.01 [.000, .022]	.01 [.000, .030]	.00 [.000, .010]	.00 [.000, .000]
		High	.29 [.222, .356]	.52 [.444, .593]	.26 [.183, .343]	.44 [.337, .557]
	Related	Medium	.11 [.070, .141]	.07 [.041, .096]	.07 [.033, .107]	.03 [.010, .067]
		Low	.01 [.000, .022]	.02 [.007, .041]	.01 [.000, .023]	.01 [.000, .017]
		High	.30 [.222, .396]	.18 [.107, .259]	.46 [.340, .583]	.29 [.190, .387]
	Unrelated	Medium	.18 [.119, .244]	.14 [.100, .200]	.15 [.097, .210]	.14 [.097, .187]
		Low	.06 [.030, .096]	.02 [.004, .037]	.03 [.003, .060]	.04 [.003, .077]
		High	.02 [.004, .031]		.05 [.025, .068]	
	Target	Medium	.02 [.007, .035]		.02 [.008, .033]	
		Low	.01 [.004, .017]		.02 [.003, .030]	
		High	.11 [.072, .150]		.13 [.085, .182]	
	Unrelated	Medium	.08 [.057, .111]		.05 [.030, .068]	
		Low	.03 [.015, .041]		.00 [.000, .005]	
		High	.33 [.244, .420]		.45 [.365, .533]	
	Unrelated	Medium	.32 [.257, .400]		.23 [.165, .292]	
		Low	.08 [.050, .120]		.07 [.023, .120]	

*Note.* Target pres. = number of target presentations. 95% confidence intervals are in brackets.

**Table 7**

*BF<sub>inclusion</sub> value for each main effect and interaction as a function of number of target presentations (1 or 4), response type (target, related, or unrelated), and age group (younger or older adults) on high confidence response proportions for each probe type (target, related and unrelated) in Experiment 2.*

Effects	Probe type		
	Target	Related	Unrelated

Target presentation	117	0.24	--
Response type	$2.79 \times 10^{56}$	$1.5 \times 10^{11}$	$7.28 \times 10^{22}$
Age group	0.27	0.48	1.08
Target presentation $\times$ Response type	$4.6 \times 10^{40}$	$1.66 \times 10^{16}$	--
Target presentation $\times$ Age group	0.2	0.3	--
Response type $\times$ Age group	17.9	1.08	0.44
Target presentation $\times$ Response type $\times$ Age group	2.25	0.13	--

### *Verbatim and gist memory*

*Verbatim, gist and guessing parameter estimates.* Verbatim, gist and guessing parameter estimates are given in Table 8. The model fitted the data well, with  $PPP \geq .30$  for all  $T_1$  and  $T_2$  statistics.

**Table 8**

*Parameter estimates for verbatim and gist memory and guessing processes as a function of number of target presentations (1 vs. 4) and age group (younger vs. older adults) in Experiment 2.*

Parameter	Younger adults		Older adults	
	Target pres. 1	Target pres. 4	Target pres. 1	Target pres. 4
$V_t$	.70 [.616, .782]	.97 [.927, .993]	.59 [.474, .711]	.93 [.878, .978]
$V_r$	.11 [.006, .251]	.35 [.109, .514]	.10 [.008, .231]	.28 [.083, .464]
$G_t$	.20 [.020, .401]	.61 [.101, .969]	.16 [.011, .395]	.39 [.031, .849]
$G_r$	.13 [.008, .280]	.22 [.017, .459]	.04 [.001, .143]	.06 [.001, .191]
$b$	.26 [.209, .315]	.26 [.207, .313]	.25 [.188, .308]	.24 [.188, .303]
$a$	.13 [.048, .233]	.14 [.057, .250]	.24 [.082, .446]	.24 [.064, .488]

*Note.* Target pres. = number of target presentations. Parameter estimates are group level means, and 95% Bayesian credible intervals are in brackets.

For each parameter, we computed a credibility interval of the difference between target presentation conditions and between age groups. The difference scores and 95% CI are shown in Table 9. As expected, verbatim memory for target probes ( $V_t$ ) increased when targets were presented four times rather than once, in both age groups. Repeated presentation of targets in the study phase also increased rejection of related probes ( $V_r$ ), particularly in

older adults. Gist memory parameters ( $G_t$  and  $G_r$ ) were not affected by the number of target presentation. Finally, there was no credible effect of age on verbatim and gist memory parameters.

**Table 9**

*Differences scores between target presentation conditions four times and once for younger and older adults and between younger and older adults in target presentation conditions once and four times in Experiment 2.*

Parameter	YA	OA	Target pres. 1	Target pres. 4
	Target pres. 4 - 1	Target pres. 4 - 1	YA - OA	YA - OA
$V_t$	<b>.26 [.174, .351]</b>	<b>.35 [.223, .469]</b>	.11 [-.038, .250]	.03 [-.027, .096]
$V_r$	.24 [-.024, .445]	<b>.21 [.009, .405]</b>	.01 [-.163, .187]	.08 [-.220, .332]
$G_t$	.43 [-.120, .850]	.22 [-.188, .711]	.04 [-.258, .303]	.22 [-.441, .784]
$G_r$	.09 [-.171, .360]	.01 [-.107, .157]	.09 [-.070, .255]	.16 [-.073, .421]
$b$	.00 [-.049, .052]	.01 [-.051, .064]	.02 [-.066, .093]	.02 [-.064, .093]
$a$	.01 [-.110, .122]	-.01 [-.172, .165]	-.11 [-.333, .078]	-.10 [-.368, .107]

*Note.* YA = younger adult; OA = older adult; Target pres. = number of target presentations.

95% credible intervals are in brackets. Bolded difference scores exclude 0 from the 95% credible interval.

## Discussion

In this second experiment, we attempted to facilitate the retrieval of verbatim traces of the studied items by presenting them multiple times rather than once. As predicted, repeated presentation of the same items increased the retrieval of verbatim representations for both younger and older adults. We also predicted that the effect of repeated presentation would be greater for older adults than for younger adults, because the former had more difficulty retrieving verbatim representations when items were presented only once. The proportion of target probes correctly identified increased with repeated presentation for both age groups. Although the correct recognition performance of younger adults in the repeated presentation condition remained superior to that of older adults, this age-related difference was reduced compared to when targets were presented only once. Thus, varying the number of item

presentations was more beneficial for older adults, for whom the gain from additional presentation was somewhat greater than for younger adults.

Repeated item presentation also favored correct identification of related distractors in both age groups. In addition, there was a main effect of the number of item presentations on the  $V_r$  parameter ( $M_{\text{diffscore}} = .24$ , 95% CI [.055, .394]), with  $V_r$  being greater when items were presented four times rather than once. This finding suggests that the increase in correct identification of related distractors when items were presented repeatedly was underpinned by an increase in recollection rejection in both age groups. However, this increase in recollection rejection was reliable only for older adults. This effect could be explained by the fact that younger adults also made more correct identifications of related distractors based on retrieval of gist representations (11%) than older adults (3%). Finally, as expected, there was no effect of age or of the target presentation manipulation on gist representations. These findings, along with those from Experiment 1, are discussed in more detail in the next section.

### **General Discussion**

We report two experiments showing for the first time that simple manipulations of information presentation can help older adults retain more elements of an episode and reduce age-related differences in episodic memory. The first experiment showed that facilitating information gist retrieval by presenting items that could be grouped into the same category substantially improved the correct recognition performance of both older and younger adults, but also led the former to make more recognition errors. The second experiment was designed to help older adults retain the details of the studied items by presenting them repeatedly. This manipulation proved effective in preserving the verbatim details of information for both older and younger adults, and the gain in correct recognition performance from repeated presentation was greater for older adults.

These findings are important from both a theoretical and an applied perspective. From a theoretical perspective, they show that age-related differences in episodic memory can be reduced by helping older adults retrieve detailed representations of an episode. These results support the theoretical proposal of a decline in the specificity of representations with age. From an applied perspective, these findings may provide clues for the development of methods aimed at facilitating the encoding of information in order to preserve the retention of episodic details in older adults. These two aspects are discussed in turn below.

### **Verbatim And, to a Lesser Extent, Gist Representations Change with Age**

The results of our two studies provide further support for the FTT's prediction that age-related deficits in episodic memory primarily affect the retrieval of verbatim representations, while gist memory is less affected (Brainerd & Reyna, 2015). The first experiment showed that older adults were less likely than younger adults to recognize target items based on the retrieval of verbatim representations. On the other hand, they relied on gist representations more often than younger adults, especially in the strong gist activation condition. The use of gist representations in this condition led them to retrieve more studied items than in the weak activation condition, but also to make more recognition errors. These findings are consistent with previous studies showing that age-related deficits in associative memory can be reduced when older adults can rely on the retrieval of gist representations (e.g., Castel, 2005).

Although age-related differences in recognition performance were reduced, they were not completely eliminated in our study. While the manipulation of gist activation by category presentation was effective in increasing retrieval of gist representations, which increased 3-fold in both older and younger adults, it may not have been strong enough to eliminate age-related differences in recognition performance. Studies have shown that taxonomic associations (e.g., apple, pear, banana, etc.) are more adversely affected by aging than thematic associations (e.g., snow, ski, sled, etc., Belacchi & Artuso, 2018). However, in the

study by Abadie et al. (2021), in which thematic associate lists (e.g., DRM lists) were used, age-related differences in recognition performance were not completely eliminated either, because again, increased retrieval of gist memory increased false recognition of related distractors, especially in older adults. Thus, an increase in the use of gist representations with age may be associated with a greater increase in memory errors. However, these are not just any errors, but semantic errors, i.e., errors that share semantic features with the actual experience. This ability to recall the gist of past episodes may give older adults certain advantages. In a variety of situations, remembering the gist of past experiences can lead to "sufficient" performance, allowing older adults to recall just enough details to avoid catastrophic memory errors (Greene & Naveh-Benjamin, 2024).

Experiment 2 showed that age-related differences in the retrieval of verbatim representations can be reduced by repeated presentation of target items during information encoding. Repeated presentation of information increases exposure time to the information and its perceptual features, resulting in increased retrieval of verbatim representations of target items, as well as correct recognition of these items, in both younger and older adults. This effect was greater for older adults, who were less likely to correctly recognize targets based on verbatim retrieval in the condition where items were presented only once. These findings are consistent with the many studies that have shown that providing participants with multiple opportunities to encode the information to be memorized enhances memory performance (e.g., Jacoby, 1999; Kilb & Naveh-Benjamin, 2011; Light et al., 2006) by promoting item recollection, particularly when items are repeated in the same context, in younger and older adults (McCormick-Huhn et al., 2018).

Recently, Greene and Naveh-Benjamin (2023) proposed a general framework for better understanding the effects of age on the quality of episodic memory representations. Overall, our results fit well within this framework. First, as proposed in the framework, our study

suggests that older adults require more exposure time to items in order to encode verbatim representations of them. Thus, it is conceivable that older adults may have difficulty in encoding verbatim representations due to the age-related slowing of information processing (Salthouse et al., 1996). Older adults would need more time or longer or more frequent exposure to the same items than younger adults to encode and retain their perceptual details. Gist representations, on the other hand, would require less time to encode and would be more likely to be encoded automatically, which is why aging would have a lesser impact on their encoding (Draine & Greenwald, 1998; Gillund & Shiffrin, 1984; Mulligan & Hirshman, 1995). In addition, studies have shown that older adults have reduced attentional capacity compared to younger adults (Naveh-Benjamin & Cowan, 2023, for a recent review). This may also account for their greater difficulty in encoding verbatim representations.

Second, as suggested in Greene and Naveh-Benjamin's framework, the fact that gist representations appear to be encoded more quickly and require fewer attentional resources than the encoding of verbatim representations may explain why older adults rely more heavily on them. As discussed above, older adults make more recognition errors than younger adults when retrieving gist representations. One possible explanation could be that the quality of retrieved gist representations varies with age, and the gist representations retrieved by older adults may be fuzzier. Alternatively, older adults could access gist representations of the same quality as younger adults, but retrieval of the item source (e.g., "Is this an item I've studied before or one I thought of when the items were presented?"), which requires attentional resources, would be affected by aging. These proposals are speculative, and future studies and/or simulations are needed to test them more rigorously. For example, future studies could distinguish between more and less fuzzy gist representations in a recognition test by manipulating the degree of semantic similarity between related distractors and the studied

items (e.g., using the supra-ordered exemplar of a category, such as fruit, vs. an unrepresented exemplar of the category, such as apple, as related distractors).

### **Encouraging Verbatim Retrieval to Improve Episodic Memory in Older Adults**

Numerous studies have shown that manipulations of information encoding, such as repeated presentation of information (e.g., Jacoby, 1999; Kilb & Naveh-Benjamin, 2011) or presentation of information in a distinctive manner (e.g., Dodson & Schacter, 2002; Koutstaal et al., 1999), improve episodic memory in older adults. For example, McCormick-Huhn et al. (2018) presented DRM lists consisting of items presented once or twice to younger and older participants. The results showed an increase in correct recognition performance for items presented twice for both younger and older adults. Repetition had no effect on false recognition of semantically related distractors in this study. Other studies have shown that repetition versus a single presentation can increase false alarm rates in older adults (e.g., Jacoby, 1999). This was particularly the case when retrieval required discrimination between items repeated in one encoding condition and those repeated in another encoding condition. The false alarms observed in older adults resulted from their difficulty in recalling the specific encoding condition. These results suggest that repeating the presentation of an item enhances memory for the item without necessarily enhancing memory for its encoding context.

Fewer studies have examined the effects of information encoding manipulations on the retrieval of verbatim and gist representations with the goal of improving memory in older adults. Those that have, focused instead on gist memory, which is preserved from the effects of aging (e.g., Castel, 2005; Castel et al., 2007, Flores et al., 2017). They revealed that older adults can compensate for the retrieval deficit of verbatim representations by increased reliance on gist representations. Encouraging the use of gist representations may, under certain conditions, equalize the memory performance between younger and older adults or even give the latter an advantage. However, as discussed above, retrieval of gist

representations also increases the rate of false alarms or memory errors in older adults (e.g., Abadie et al., 2021). The present study is the first to examine the effect of a manipulation designed to improve retrieval of verbatim representations in older adults. Previous studies have suggested that repetition of item presentation may be an effective manipulation to enhance retrieval of the items themselves and thus verbatim representations (e.g., McCormick-Huhn et al., 2018, Jacoby et al., 1999). The results of the present study fully confirmed this intuition. Older adults correctly identified items presented only once 59% of the time based on verbatim retrieval, whereas they correctly identified items presented four times 93% of the time based on verbatim retrieval. Correct identification of related items based on verbatim retrieval was multiplied by three by the number of times the items were presented. Thus, a simple manipulation of information encoding, such as item repetition, may help older adults retrieve more specific memories of an event. These findings seem promising, and it is important that future studies continue in this direction by examining whether other encoding manipulations, such as varying the number of repetitions, increasing the processing time of the items, or instructing participants to process the perceptual details of the items, could help older adults retrieve specific representations and thus reduce the effects of age on episodic memory. In these recent developments (Brainerd et al., 2022), the FTT proposes to distinguish between retrieval of the items themselves based on retrieval of their verbatim traces, retrieval of the context in which the items were presented (e.g., position, color, font, apparatus details, thoughts, etc.), and the feeling of familiarity associated with retrieval of the gist traces of the items. Our study showed that repeated presentation of the items improved verbatim retrieval, but it is possible that this manipulation also favors retrieval of the context in which the items were presented. Future studies may be able to determine whether retrieval of the context associated with item presentation is also affected by aging and whether encoding manipulations can improve it. These studies may not only improve our

understanding of the effects of aging on the specificity of episodic representations but may also allow us to develop new methods to improve episodic memory in older adults.

### **Limitations**

The present study is not without its limitations. The first was that the gist activation manipulation (Exp. 1) and the repetition manipulation (Exp. 2) were executed within subjects. The processing of the gist of the items in multiple-exemplar categories (Exp.1) and the processing of the verbatim of the items presented multiple times (Exp.2) could have interfered with the processing of the other items. This could have the consequence of strengthening the main effect of the gist activation and repetition manipulations on recognition performance by artificially decreasing the recognition performance of items in single-exemplar categories and those presented only once. However, if this were indeed the case, there is no reason to believe that the effect would be different for younger and older adults. Consequently, this would not have confounded the interactions between age and the gist activation and repetition manipulations. Moreover, the fact that the gist activation manipulation had the predicted effect specifically on gist representations without affecting verbatim representations seems to contradict the hypothesis of an interference effect affecting the processing of single-exemplar categories, since there is no clear reason why it should affect gist retrieval more than verbatim retrieval. The same is true for the repetition manipulation, which specifically affected verbatim representations without affecting gist representations. However, it is important that future experiments perform these manipulations between subjects to completely rule out the interference hypothesis.

Second, the multiple-exemplar categories in Experiment 1 were presented randomly, whereas in the classic DRM procedure (Roediger & McDermott, 1995), multiple-exemplar categories were presented blocked per category. Thus, our manipulation might not have been strong enough to promote gist formation and retrieval of these categories. However, our

results showed an increase in gist memory between the strong and weak gist conditions for both younger adults (i.e., 56% increase for targets and 40% increase for related distractors) and older adults (i.e., 48% increase for targets and 33% increase for related distractors). Therefore, it appears that the gist activation manipulation in the present study was effective in increasing gist memory in both younger and older adults. We expected that enhancing gist memory retrieval would be particularly beneficial for recognition performance in older adults, in whom gist representations are preserved from the effects of age. However, our results showed that this manipulation improved recognition performance for both younger and older adults. It was not more beneficial for older adults, as gist activation also led them to make more recognition errors. Future studies could test whether the increase in gist memory might be even greater when items belonging to the same category are presented in blocks rather than randomly, and whether the interaction with age might then appear in recognition performance.

### **Conclusion**

This study showed that simple manipulations of information encoding can be used to reduce age-related differences in episodic memory. Facilitating the retrieval of gist or the retention of details of presented information improved recognition performance in younger and older adults and reduced age-related differences by increasing the retrieval of gist or verbatim representations. These findings support the principle that age-related changes in representational specificity explain differences in episodic memory between younger and older adults.

## **Declarations**

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### **Conflicts of interest/Competing interests**

The authors declare that they have no conflicts of interest to report.

### **Ethics approval**

This study was approved by the Aix-Marseille University Institutional Review Board, Project Number 20220113002.

### **Consent to participate**

All participants provided informed consent prior to participating.

### **Available data and materials**

Materials, data and data analysis files for both experiments are available at [https://osf.io/v4h3y/?view\\_only=f2e714c41d5a44919d44ae4fb533df15](https://osf.io/v4h3y/?view_only=f2e714c41d5a44919d44ae4fb533df15). None of the experiments were preregistered.

### **Code availability**

Not applicable.

## References

- Abadie, M., Gavard, E., & Guillaume, F. (2021). Verbatim and gist memory in aging. *Psychology and Aging, 36*(8), 891-901. <https://doi.org/10.1037/pag0000635>
- Belacchi, C., & Artuso, C. (2018). How taxonomic and thematic associations in semantic memory modulate recall in young through old-old adults. *Psychology and Aging, 33*, 1060-1069. <https://doi.org/10.1037/pag0000297>
- Bonin, P., Méot, A., Ferrand, L., & Bugańska, A. (2013). Normes d'associations verbales pour 520 mots concrets et étude de leurs relations avec d'autres variables psycholinguistiques. *L'Année psychologique, 113*(1), 63-92. <https://doi.org/10.3917/anpsy.131.0063>
- Brainerd, C. J. (2021). Deep memory distortions. *Cognitive Psychology, 126*, 101386. <https://doi.org/10.1016/j.cogpsych.2021.101386>
- Brainerd, C. J. (2022). Deep distortion. *Memory, 30*(1), 5-9.
- Brainerd, C. J., Bialer, D. M., & Chang, M. (2022). Fuzzy-trace theory and false memory: Meta-analysis of conjoint recognition. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 48*(11), 1680-1697.
- Brainerd, C. J., Gomes, C. F. A., & Moran, R. (2014). The two recollections. *Psychological Review, 121*, 563–599. <https://doi.org/10.1037/a0037668>
- Brainerd, C. J., Gomes, C. F. A., & Nakamura, K. (2015). Dual recollection in episodic memory. *Journal of Experimental Psychology: General, 144*, 816-843. <https://doi.org/10.1037/xge0000084>.
- Brainerd, C. J., & Reyna, V. F. (2010). Recollective and nonrecollective recall. *Journal of Memory and Language, 63*, 425-445. <https://doi.org/10.1016/j.jml.2010.05.002>.
- Brainerd, C. J., & Reyna, V. F. (2015). Fuzzy-trace theory and lifespan cognitive development. *Developmental Review, 38*, 89–121. <https://doi.org/10.1016/j.dr.2015.07.006>.

- Brainerd, C. J., Reyna, V. F., & Howe, M. L. (2009). Trichotomous processes in early memory development, aging, and neurocognitive impairment: a unified theory. *Psychological Review*, *116*, 783–832. <https://doi.org/10.1037/a0016963>.
- Brainerd, C. J., Reyna, V. F., & Mojardin, A. H. (1999). Conjoint recognition. *Psychological Review*, *106*, 160-179. <https://doi.org/10.1037/0033-295X.106.1.160>.
- Brainerd, C. J., Reyna, V. F., Petersen, R. C., Smith, G. E., & Taub, E. S. (2011). Is the apolipoprotein E genotype a biomarker for mild cognitive impairment? Findings from a nationally representative study. *Neuropsychology*, *25*, 679 – 689. <https://doi.org/10.1037/a0024483>
- Brainerd, C. J., Reyna, V. F., Petersen, R. C., Smith, G. E., Kenney, A. E., Gross, C. J.,...Fisher, G. G. (2013). The apolipoprotein E genotype predicts longitudinal transitions to mild cognitive impairment but not to Alzheimer’s dementia: Findings from a nationally representative study. *Neuropsychology*, *27*, 86 –94. <https://doi.org/10.1037/a0030855>
- Brainerd, C. J., Wright, R., Reyna, V. F., & Mojardin, A. H. (2001). Conjoint recognition and phantom recollection. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *27*, 307–327. <https://doi.org/10.1037/0278-7393.27.2.307>
- Castel, A. D. (2005). Memory for grocery prices in younger and older adults: The role of schematic support. *Psychology and aging*, *20*, 718-721. <https://doi.org/10.1037/0882-7974.20.4.718>
- Castel, A. D., Farb, N. A. S., & Craik, F. I. M. (2007). Memory for general and specific value information in younger and older adults: Measuring the limits of strategic control. *Memory & Cognition*, *35*(4), 689–700. <https://doi.org/10.3758/BF03193307>
- Castel, A. D., McGillivray, S., & Worden, K. M. (2013). Back to the future: Past and future era-based schematic support and associative memory for prices in younger and older adults. *Psychology and Aging*, *28*(4), 996–1003. <https://doi.org/10.1037/a0034160>

- Devitt, A. L., & Schacter, D. L. (2016). False memories with age: Neural and cognitive underpinnings. *Neuropsychologia*, *91*, 346-359. <https://doi.org/10.1016/j.neuropsychologia.2016.08.030>
- Dodson, C. S., & Schacter, D. L. (2002). Aging and strategic retrieval processes: Reducing false memories with a distinctiveness heuristic. *Psychology and Aging*, *17*(3), 405-415. <https://doi.org/10.1037/0882-7974.17.3.405>
- Draine, S. C., & Greenwald, A. G. (1998). Replicable unconscious semantic priming. *Journal of Experimental Psychology: General*, *127*(3), 286-303. <https://doi.org/10.1037/0096-3445.127.3.286>
- Faul, F., Erdfelder, E., Buchner, A., & Lang, A. G. (2009). Statistical power analyses using G\* Power 3.1: Tests for correlation and regression analyses. *Behavior Research Methods*, *41*(4), 1149-1160. <https://doi.org/10.3758/BRM.41.4.1149>
- Flores, C. C., Hargis, M. B., McGillivray, S., Friedman, M. C., & Castel, A. D. (2017). Gist-based memory for prices and “better buys” in younger and older adults. *Memory*, *25*, 565-573. <https://doi.org/10.1080/09658211.2016.1197944>.
- Gallo, H. B., Hargis, M. B., & Castel, A. D. (2019). Memory for weather information in younger and older adults: Tests of verbatim and gist memory. *Experimental aging research*, *45*, 252-265. <https://doi.org/10.1080/0361073X.2019.1609163>.
- Gillund, G., & Shiffrin, R. M. (1984). A retrieval model for both recognition and recall. *Psychological Review*, *91*(1), 1-67. <https://doi.org/10.1037/0033-295X.91.1.1>
- Greene, N. R., & Naveh-Benjamin, M. (2020). A specificity principle of memory: Evidence from aging and associative memory. *Psychological Science*, *31*, 316-331. <https://doi.org/10.1177/0956797620901760>

- Greene, N. R., & Naveh-Benjamin, M. (2022a). Adult age differences in specific and gist associative episodic memory across short- and long-term retention intervals. *Psychology and Aging, 37*(6), 681–697. <https://doi.org/10.1037/pag0000701>
- Greene, N. R., & Naveh-Benjamin, M. (2022b). The effects of divided attention at encoding on specific and gist-based associative episodic memory. *Memory & Cognition, 50*(1), 59–76. <https://doi.org/10.3758/s13421-021-01196-9>
- Greene, N. R., & Naveh-Benjamin, M. (2023). Adult age-related changes in the specificity of episodic memory representations: A review and theoretical framework. *Psychology and Aging, 38*(2), 67–86. <https://doi.org/10.1037/pag0000724>
- Greene, N. R., & Naveh-Benjamin, M. (2024). On the adaptive reliance on fuzzy memory representations in adult aging. In M. Toglia, H. Otgaar, J. Altarriba, & W. Erickson (Eds.), *Interdisciplinary perspectives and advances in understanding adaptive memory*. Oxford University Press.
- Heck, D. W., Arnold, N. R., & Arnold, D. (2018). TreeBUGS: An R package for hierarchical multinomial-processing-tree modeling. *Behavioral Research Methods, 50*, 264–284. <https://doi.org/10.3758/s13428-017-0869-7>
- Jacoby, L. L. (1999). Ironic effects of repetition: Measuring age-related differences in memory. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 25*(1), 3–22. <https://doi.org/10.1037/0278-7393.25.1.3>
- JASP Team (2023). JASP (Version 0.17.3) [Computer software].
- Kilb, A., & Naveh-Benjamin, M. (2011). The effects of pure pair repetition on younger and older adults' associative memory. *Journal of Experimental Psychology-Learning Memory and Cognition, 37*(3), 706–719. <https://doi.org/10.1037/A0022525>

- Kim, S., Goldstein, D., Hasher, L., & Zacks, R. T. (2005). Framing effects in younger and older adults. *Journals of Gerontology: Series B: Psychological Sciences and Social Sciences*, *60*(4), 215–218. <https://doi.org/10.1093/geronb/60.4.P215>
- Klauer, K. C. (2010). Hierarchical multinomial processing tree models: A latent-trait approach. *Psychometrika*, *75*, 70–98. <https://doi.org/10.1007/s11336-009-9141-0>
- Koutstaal, W., & Schacter, D. L. (1997). Gist-based false recognition of pictures in older and younger adults. *Journal of Memory and Language*, *37*, 555–583. <https://doi.org/10.1006/jmla.1997.2529>
- Koutstaal, W., Schacter, D. L., Galluccio, L., & Stofer, K. A. (1999). Reducing gist-based false recognition in older adults: Encoding and retrieval manipulations. *Psychology and Aging*, *14*(2), 220–237. <https://doi.org/10.1037/0882-7974.14.2.220>
- Kruschke, J. K. (2011). Bayesian assessment of null values via parameter estimation and model comparison. *Perspectives on Psychological Science*, *6*, 299–312. <https://doi.org/10.1177/1745691611406925>
- Kruschke, J. K. (2018). Rejecting or accepting parameter values in Bayesian estimation. *Advances in Methods and Practices in Psychological Science*, *1*, 270–280. <https://doi.org/10.1177/2515245918771304>
- Light, L. L., Chung, C., Pendergrass, R., & Van Ocker, J. C. (2006). Effects of repetition and response deadline on item recognition in young and older adults. *Memory & Cognition*, *34*(2), 335–343. <https://doi.org/10.3758/BF03193411>
- McCormick-Huhn, J. M., Bowman, C. R., & Dennis, N. A. (2018). Repeated study of items with and without repeated context: aging effects on memory discriminability. *Memory*, *26*(5), 603–609. <https://doi.org/10.1080/09658211.2017.1387267>

- Mulligan, N., & Hirshman, E. (1995). Speed-accuracy trade-offs and the dual process model of recognition memory. *Journal of Memory and Language*, *34*(1), 1-18.  
<https://doi.org/10.1006/jmla.1995.1001>
- Nasreddine, Z. S., & Patel, B. B. (2016). Validation of Montreal cognitive assessment, MoCA, alternate French versions. *Canadian Journal of Neurological Sciences*, *43*(5), 665-671. <https://doi.org/10.1017/cjn.2016.273>
- Nasreddine, Z. S., Phillips, N. A., Bédirian, V., Charbonneau, S., Whitehead, V., Collin, I., ... & Chertkow, H. (2005). The Montreal Cognitive Assessment, MoCA: a brief screening tool for mild cognitive impairment. *Journal of the American Geriatrics Society*, *53*(4), 695-699.
- Naveh-Benjamin, M., & Cowan, N. (2023). The roles of attention, executive function and knowledge in cognitive ageing of working memory. *Nature Reviews Psychology*, *2*(3), 151-165. <https://doi.org/10.1038/s44159-023-00149-0>
- Norman, K. A., & Schacter, D. L. (1997). False recognition in younger and older adults: Exploring the characteristics of illusory memories. *Memory & Cognition*, *25*(6), 838-848. <https://doi.org/10.3758/BF03211328>
- R Core Team (2023). R: A language and environment for statistical computing. RStudio version 4.3.1, (2023-06-16), [Computer Software]. Vienna, Austria. Retrieved from <https://www.R-project.org/>.
- Reyna, V. F., & Brainerd, C. J. (2011). Dual processes in decision making and developmental neuroscience: a fuzzy-trace model. *Developmental Review*, *31*, 180-206.  
<https://doi.org/10.1016/j.dr.2011.07.004>.
- Roediger, H. L., & McDermott, K. B. (1995). Creating false memories: Remembering words not presented in lists. *Journal of Experimental Psychology*, *21*, 803-814. <https://doi.org/10.1037/0278-7393.21.4.803>

- Rouder, J. N. (2014). Optional stopping: No problem for Bayesians. *Psychonomic Bulletin & Review*, *21*, 301-308. <https://doi.org/10.3758/s13423-014-0595-4>
- Rouder, J.N., Morey R.D., Speckman P.L., & Province J M. (2012). Default Bayes factors for ANOVA designs. *Journal of Mathematical Psychology*, *56*, 356-374.
- Salthouse, T. A. (1996). The processing-speed theory of adult age differences in cognition. *Psychological Review*, *103*(3), 403–428. <https://doi.org/10.1037/0033-295X.103.3.403>
- Schmidt, O., Erdfelder, E., & Heck, D. W. (2022). Tutorial on multinomial processing tree modeling: How to develop, test, and extend MPT models. *Psychol. Methods*, *10*.
- Smith, J. B., & Batchelder, W. H. (2010). Beta-MPT: Multinomial processing tree models for addressing individual differences. *Journal of Mathematical Psychology*, *54*, 167-183. <https://doi.org/10.1016/j.jmp.2009.06.007>
- Stahl, C., & Klauer, K. C. (2008). A simplified conjoint recognition paradigm for the measurement of gist and verbatim memory. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *34*, 570-586. <https://doi.org/10.1037/0278-7393.34.3.570>.
- Tun, P. A., Wingfield, A., Rosen, M. J., & Blanchard, L. (1998). Response latencies for false memories: Gist-based processes in normal aging. *Psychology and Aging*, *13*, 230–241. <https://doi.org/10.1037/0882-7974.13.2.230>.
- van Doorn, J., van den Bergh, D., Böhm, U., Dablander, F., Derks, K., Draws, T., Etz, A., Evans, N.J., Gronau, Q.F., Haaf, J.M., Hinne, M., Kucharský, S., Ly, A., Marsman, M., Matzke, D., Gupta, A.R.K.N., Sarafoglou, A., Stefan, A., Voelkel, J. G., & Wagenmakers, E.-J. (2021). The JASP guidelines for conducting and reporting a Bayesian analysis. *Psychonomic Bulletin & Review*, *28*(3), 813–826. <https://doi.org/10.3758/s13423-020-01798-5>