Gist more than non-gist representation interferes with associative memory in older adults: The role of inhibitory function

Jia-Jie Xu[1], Jun-Yi Chen[1], Hong-Zhou Xu[1], Zhi-Wei Zheng[2,3]*, Jing Yu[1]*

[1]Faculty of Psychology, Southwest University, Chongqing, China

[2]Center on Aging Psychology, CAS Key Laboratory of Mental Health, Institute of Psychology, Chinese Academy of Sciences, Beijing, China

[3]Department of Psychology, University of Chinese Academy of Sciences, Beijing, China

*Corresponding authors:

Zhi-Wei Zheng, Center on Aging Psychology, CAS Key Laboratory of Mental Health, Institute of Psychology, Chinese Academy of Sciences, No. 16 Lincui Road, Chaoyang District, Beijing 100101, China. E-mail address: zhengzw@psych.ac.cn

Jing Yu, Faculty of Psychology, Southwest University, Tiansheng Road, Beibei District, Chongqing 400715, China. E-mail address: helen12@swu.edu.cn

Abstract

Associative memory deteriorates with age. One possible reason for this associative memory deficit in older adults is a deterioration in inhibitory function. However, it remains unclear whether gist representations are more likely to interfere with older adults' associative memory than non-gist representations and what role of inhibitory function plays in age-related associative memory deficits, as well as whether and how acute inhibitory function training could ameliorate the detrimental effects of inhibitory deficits on associative memory in older adults. In Experiment 1, 80 participants (40 younger and 40 older adults) studied scene-word pairs while attempting to inhibit interfering words during encoding. An immediate associative recognition memory test was performed, followed by a modified Stroop task to measure the inhibitory function. Experiment 2 included 66 older adults randomly assigned to either an inhibitory function acute-training or a control group. The Flanker task was employed for acute inhibitory function intervention, and eye-tracking technology was used to record eye movement indicators. The results showed that older adults showed more gist memory under gist representation interference, and inhibitory function mediated the relationship between age and associative memory accuracy. Notably, although acute inhibitory training did not improve associative memory accuracy, the older adults in the acute-training group exhibited shorter fixation durations and frequencies within the interference region, and then made less inaccurate response in associative memory recognition, leading to better associative memory. These findings elucidate that gist representation more than non-gist interferes with associative memory in older adults, and inhibitory deficits play a mediation role in age-related associative memory decline, as well as the feasibility of inhibitory training to improve associative memory. Our study provides direction for clinical interventions targeting associative memory improvement.

***Keywords**:* aging, associative memory, inhibitory function training, conditional process analysis, structural equation modelling.

Introduction

Associative memory deteriorates with age. On the one hand, the ability older adults to establish associations between components is reduced compared to young adults (Naveh-Benjamin, 2000; Naveh-Benjamin et al., 2003, 2004; Old & Naveh-Benjamin, 2008); on the other hand, older adults have deficits in inhibitory control and have difficulty suppressing irrelevant thoughts and actions, which affects the accuracy of associative memory (Hasher, 2015; Hasher & Zacks, 1988; Lustig et al., 2007). However, the characteristics of the interfering stimuli and their relationship to established associative representations are less studied. Specifically, whether older adults can inhibit gist-related interference when there are multiple associations generative of a gist representation. One possibility is that older adults have limited cognitive resources and that the association itself is difficult for them, so there may be no differences when the interfering stimuli are gist-related or non-gist-related. However, on the other hand, the formation of gist representations is automated and independent of the formation of verbatim representations (Greene & Naveh-Benjamin, 2023a, 2023b), so as older adults' inhibitory control declines, they may show a greater interference effect of gist-related stimuli compared to younger counterparts.

The fuzzy trace theory proposes that episodic memories are encoded with two separate traces: a verbatim trace, which captures the specific details of an episode, and a gist trace, which captures meaning or semantic features (Brainerd & Reyna, 1990, 2004; Reyna & Brainerd, 1995). Recent studies have provided converging evidence that age-related deficits in associative memory are limited to the retrieval of verbatim representations, whereas gist representations are more likely to be retained (Abadie et al., 2021; Greene & Naveh-Benjamin, 2020). In addition, studies have found that gist memory is more resistant to interference than verbatim memory (Brainerd & Reyna, 2002; Reyna, 1995). Nevertheless, research on the interference effect of gist and verbatim memory has mainly come from experiments involving attentional distraction. For example, when attention is distracted during encoding, younger individuals show reduced verbatim memory compared to gist memory (Greene & Naveh-Benjamin, 2022a, 2022b). In the present study, we manipulated the characteristics of interfering stimuli to directly examine the age effect of interference on gist and verbatim representations of associative memory. Specifically, based on an associative memory paradigm involving verbatim and gist representations (Greene & Naveh-Benjamin, 2022a, 2022b), interfering words are presented in gist-related and non-gist-related conditions.

In addition to the formation of verbatim and gist representations of associative memory, inhibitory control plays a critical role in this task. We tested participants' inhibitory function using a modified Stroop task, and used conditional processing analysis to examine the role of inhibitory function in the relationship between age and associative memory performance. Furthermore, we examined whether improvements in inhibitory control might be reflected in older adults' associative memory. Accumulating empirical evidence suggests that the targeted training of inhibitory function holds promise for improving memory performance in older adults (Chiu et al., 2018; Ji et al., 2016; Nguyen et al., 2019; Xu et al., 2023). However, it remains uncertain whether and how acute inhibitory function training could ameliorate the detrimental effects of inhibitory deficits on the gist and verbatim representations of associative memory in older adults. Experiment 2 was designed to systematically examine the effects of acute inhibitory training on associative memory in older adults. Eye-tracking was used to record eye movement indices during memory encoding with the aim of accessing the influence of interfering stimuli. We hypothesized that acute training of inhibitory would improve associative memory performance in older adults. In addition, using structural equation modelling, we examined the role of acute inhibitory training on older adults' associative memory.

In two experiments of the present study, we asked four questions (see Table 1 for details) that: (1) Does gist stimuli interfere more than non-gist stimuli with associative memory in older adults? (2) How does inhibitory function affect the relationship between age and associative memory? (3) Does acute inhibitory training improve the associative memory of older adults? and (4) How does acute inhibitory function training improve the associative memory of older adults? We employed the modified simplified-conjoint-recognition (SCR) paradigm to compare gist-related and non-gist-related interfering stimuli on associative memory. The multinomial-processing-tree (MPT) model was used to measure the representations of verbatim and gist memory (Stahl & Klauer, 2008). In Experiment 2, we used eye-tracking to accurately capture the benefits of acute inhibitory training. Conditional process analysis and structural equation modelling were also employed to analyze the potential pathways between inhibitory deficits and acute-training effect and associative memory.

Table 1. Design table

Experiment No.	Question	Hypothesis	Analysis	Interpretation given to outcomes
Experiment 1	1. Does gist representation more than non-gist interfere with associative memory in older adults?	Two hypotheses: (H1a) There will be no significant difference in the interference effect between gist and non-gist words; (H1b) The interference effect of gist representations will be stronger in older adults.	We will run MPT models in younger and older adults separately, and analyze the significant differences between gist and non-gist interference among MPT model parameters.	The results are consistent with the H1a if model parameters for which the 95% CI of the condition difference estimate included 0, otherwise consistent with H1b.
	2. How does inhibitory function affect the relationship between age and associative memory accuracy?	(H2) Inhibitory function will mediate the relationship between age and associative memory.	We will conduct a conditional process analysis using PROCESS in SPSS, while controlling for years of education as a covariate.	The results are consistent with the hypothesis if any indirect pathway effect which includes inhibitory function as a mediation is statistically significant ($p < 0.05$).

Experiment 2	3. Can acute inhibitory function training improve older adults' associative memory?	(H3) Acute inhibitory function training will improve older adults' associative memory.	We will conduct T-tests on associative memory accuracy between acute training and control group.	The results are consistent with the hypothesis if the accuracy in acute training group is significantly greater than that in control group ($p < 0.05$).
	4. How does acute inhibitory function training improve older adults' associative memory?	(H4) Acute inhibitory function training will reduce the effect of gist-related interference and then improve older adults' associative memory.	We will use structural equation modeling to examine the relationships among variables, including groups, eye movement parameters, R-I, and ACC. Specifically, a latent variable was constructed using four significant eye movement parameters in the interfering word AOI as proxies.	The results are consistent with the hypothesis if any indirect pathway effect which includes eye-tracking latent variable as a mediation is statistically significant ($p < 0.05$).

Experiment 1

Methods

Transparency and openness. All procedures of Experiments 1 and 2 were approved by the Institutional Review Board (IRB) of the Faculty of Psychology, Southwest University (IRB number H22113). To support transparency and openness, all data, materials, and analysis scripts are available at OSF: https://osf.io/793ge/**.** Experiment 1 was pre-registered with Aspredicted: https://aspredicted.org/tq9uq.pdf. Experiment 2 has been pre-registered at https://aspredicted.org/5hc9a.pdf.

Participants**.** Eighty healthy younger and older adults were recruited from Southwest University and the local community. Participants were native Chinese speakers with normal or corrected-to-normal vision and hearing, and free of neurological and psychiatric disorders. Older adults with a score above 25 on the Mini-Mental State Examination (MMSE; Folstein et al., 1975) were included in the experiment (MMSE range: 26-30; *M* = 28.98, *SD* = 1.11). Data from one older adult were excluded because she performed below the guessing level on the memory task (ID: 13; *ACC* = 0.30). As a result, 39 older adults (33 female; age range: 57-78 years; *M* = 69.10, *SD* = 5.20; years of education: *M* = 10.15, *SD* = 2.29) and 40 younger adults (33 female; age range: 18-27 years; *M* = 21.6, *SD* = 2.25; years of education: *M* = 15.68, *SD* = 2.14) were included for subsequent statistical analyses.

Stimuli**.** The stimuli consisted of 120 scene pictures, 120 target words, and 60 interfering words. Each scene picture was paired with a target word and an interfering word, and every two consecutive interfering words were the same, resulting in 120 scene -words pairs in the study phase. Scene pictures were drawn from a scene pool of different scene categories (Konkle et al., 2010), and within a given scene category, two pictures were randomly selected. Scene categories were not repeated across the trials. Target words were taken from the original Deese-Roediger-McDermott (DRM; Deese, 1959; Roediger & McDermott, 1995) list. There are two types of interfering words (gist and non-gist words). Gist words are lure words in the given DRM lists, while non-gist words are new words with no semantic correlation.

The 120 pairs were divided into six experimental blocks and two practice blocks. Each experimental block consisted of 16 scene-words pairs, for a total of 96 pairs. Each practice block contained 12 scene-words pairs, for a total of 24 pairs. The scene pictures in every two consecutive stimuli were from the same scene category, e.g., two pictures of a treehouse (see Figure 1). In addition, the target words combined with the scene pictures from the same category were from the same DRM list, e.g., “nap” and “yawn” from one DRM list. Thus, the two successive scene-words pairs formed a gist memory of “treehouse-sleep,” with the interfering word set as either the gist word “sleep” or the non-gist word condition. Stimulus pairs were presented using E-prime 2.0 software (Schneider, 2012), and the experiments were conducted in a standardized behavioral laboratory at Southwest University.

Prior to the experiment, we recruited 30 older and 30 younger adults to complete a materials assessment in which the participants were asked to rate on a scale of 1 to 7 how closely the two words were semantically related to the gist word. Results showed that gist pairs (two words and one gist word) had a higher score (M = 6.55, SD = 0.34) than non-gist pairs (two words and one non-gist word; M = 1.26, SD = 0.33; t = 62.44, p < 0.001).

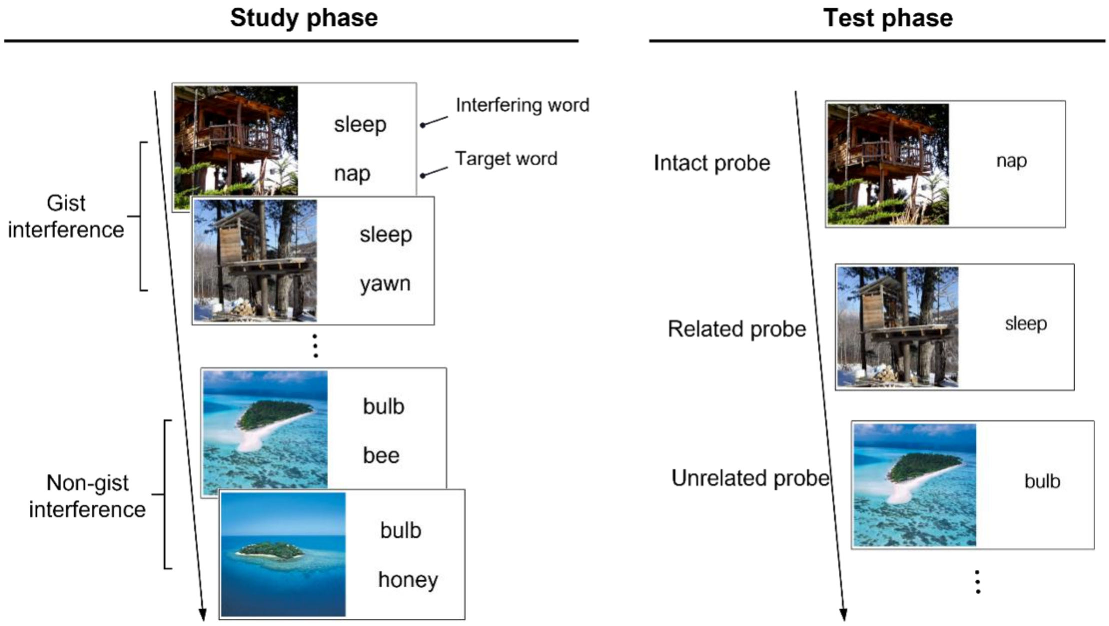

Figure 1. Schematic of the procedure in Experiment 1. In the study phase, participants were instructed to memorize the pairs of scene picture and the word at the bottom and to ignore the interfering word at the top (positions counterbalanced across subjects). Every two consecutive pairs formed a gist memory. Interfering words consisted of gist words (i.e., gist interference) and non-gist words (i.e., non-gist interference). In the test phase, participants were instructed to decide whether the given picture-word pair was "intact", "related", or "unrelated". Intact probes are picture-word pairs that have been presented previously. Related probes are pairs of scene pictures with interfering words but the gist of the given target words, and unrelated probes are pairs of scene pictures with interfering words but not semantically related to the given target words.

***Procedure*.** Each participant completed the experiment individually in the presence of an experimenter in the laboratory. The experiment lasted approximately one hour. Each block consisted of a study phase and a test phase (see Figure 1). During the study phase, each scene-words pair was presented on the screen for 4 s, followed by a blank screen for 0.3-0.8 s to prevent anticipation. Participants were instructed to remember the picture and the word at the bottom and to ignore the interfering word at the top. The position of the two types of words on the screen was counterbalanced across participants. Participants were informed that there were no repeated pictures or target words. Sixteen scene-words pairs in a block were presented pseudorandomly, with the constraint that two pairs of the same gist memory were presented consecutively in the same block. The study phase of each block was followed by a 5-s interval, after which the test phase began.

During the test phase, 16 scene-word pairs were randomly presented one at a time (see Figure 1), including five intact probes, six related probes, and five unrelated probes. Intact probes presented a scene-word pair previously presented in the study phase, e.g., "treehouse picture 1" paired with "nap". Related probes were a combination of the presented scene picture and a gist interfering word. The scene picture was presented in the study phase; the gist word, although also presented, was asked to be ignored in the study phase. Unrelated probes were the combination of the presented scene picture and a new non-gist word. They were instructed to judge whether the scene-word pairs presented on the screen had been studied in the previous phases. If so, they were instructed to press "a" on the keyboard. If not, they were asked to judge whether the new paired word had a semantic relationship with the old paired word. If yes, they were instructed to press "f"; if no, they were instructed to press "j". There was no time limit for responding. Given the known age differences in learning, we adjusted for task difficulty between age groups (Sander et al., 2021). Specifically, older adults took a test every time they learned a block, whereas the younger adults took a test every two blocks.

Two minutes after the memory test, participants were asked to complete a Stroop task (Stroop, 1935) to assess their inhibitory function. In the modified Stroop task, participants were instructed to judge whether the color of the word matched the meaning of the word. If it did, they were to press the "d" key, and if it did not, they were to press the "h" key. The task consisted of 12 practice and 80 formal trials, including 40 consistent and 40 inconsistent trials.

Data analyses

Response proportion. For each probe (i.e., intact, related, and unrelated), the proportions of responses under different conditions (gist interference vs. non-gist interference) were calculated separately for older and younger adults. ANOVA was then used to examine the age by condition interaction effect for correct and incorrect responses in each probe.

MPT model. The multinomial-processing-tree (MPT) model was utilized to differentiate and quantify verbatim and gist memory, which is reflected in the corresponding parameters V and G. We used the *TreeBUGS* package for R (Heck et al., 2018; Team, 2020) to run the model separately in both age groups to compare the differences between the gist and non-gist interference conditions. Forest plots were then used to visually display the interference condition differences in younger and older adults, respectively. Parameters for which the 95% CI of the difference estimate included 0 indicated that there was no significant difference between conditions (Smith & Batchelder, 2010). Additional information on the MPT model can be found in the Supplemental Material.

Inhibitory Function Index (IF) from Stroop task. The response time (RT) in the consistent condition was subtracted from the RT in the inconsistent condition and then divided by the RT in the consistent condition. For ease of interpretation, the above score was subtracted from a larger number (i.e., two). Thus, the higher the score, the better the inhibitory function. In addition, to account for the trade-off between accuracy and speed, the reaction time was multiplied by the score. Therefore, the final equation is as follows:

$$\mathrm{IF} = \mathrm{ACC} * [2 - \frac{RT_{inconsistent} - RT_{consistent}}{RT_{consistent}}]$$

Conditional process analysis. To explore the underlying mechanisms between age, inhibitory function, and memory performance, a conditional process analysis (Hayes & Rockwood, 2020) was conducted using PROCESS in SPSS (http://www.afhayes.com), while controlling for years of education as a covariate.

Results

Response proportion. The response proportions of older and younger adults in the gist and non-gist interference conditions for three probe types (intact, related, and unrelated probe) are shown in Figure 2. For accuracy (i.e., participants responded "intact" to intact probes, "related" to related probes, and "unrelated" to unrelated probes), the accuracy of older adults was significantly lower than that of younger adults for intact probes (t = 4.68; p < 0.001, Cohen's d = 0.75) and related probes (t = 10.51; p < 0.001, Cohen's d = 1.68), whereas there was no significant age group difference on unrelated probes (t = 1.77; p = 0.08, Cohen's d = 0.28).

For the proportion of incorrect responses, as shown in Figure 2, older adults had similar patterns to younger adults for intact and unrelated probes, indicating that the proportion of incorrect "related" responses was significantly higher than the proportion of other responses (intact probe: t = 3.42; p < 0.001, Cohen's d = 0.38; unrelated probe: t = 5.48; p < 0.001, Cohen's d = 0.42). For related probes, there was a significant interaction effect of age and interference condition on the proportion of incorrect "intact" responses (related incorrectly identified as intact, R-I; F(1, 154) = 3.96, $\eta 2$ = 0.02, p = 0.04). The simple effects results showed that for older adults, the gist interference condition had a significantly higher proportion of RI than the non-gist interference condition (t = 2.67; p =

0.009, Cohen's *d* = 0.63), whereas for younger adults, there was no significant difference in RI between the two interference conditions (t = 1.55; p = 0.13, Cohen's d = 0.35).

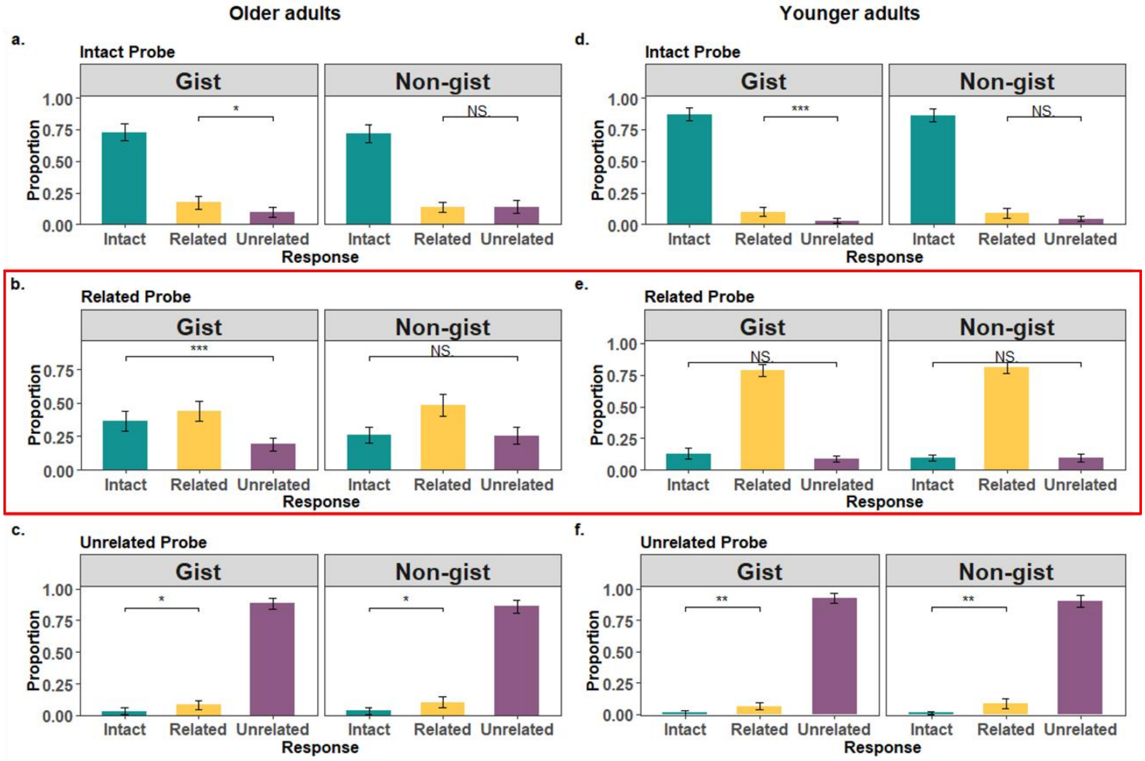

Figure 2. Response proportions of older adults (a, b, c) and younger adults (d, e, f) in the gist interference and non-gist interference in three probe types (intact, related, and unrelated probe). The red box shows the interaction effect of age and interference condition on the proportion of related incorrectly identified as intact, R-I . Note: *p < 0.05; **p < 0.01; ***p < 0.001, NS= not significant.

MPT results. Figure 3 shows the interference differences for each parameter obtained by subtracting the non-gist from the gist condition in younger and older adults, respectively. There were no significant differences in the parameters between conditions in younger adults (Figure 3a), while older adults showed significantly higher values of G_i and G_r in the gist interference condition compared to the non-gist condition (Figure 3b). Details of the parameter estimates for each interference condition in younger and older adults are shown in Table S1 in the Supplemental Material.

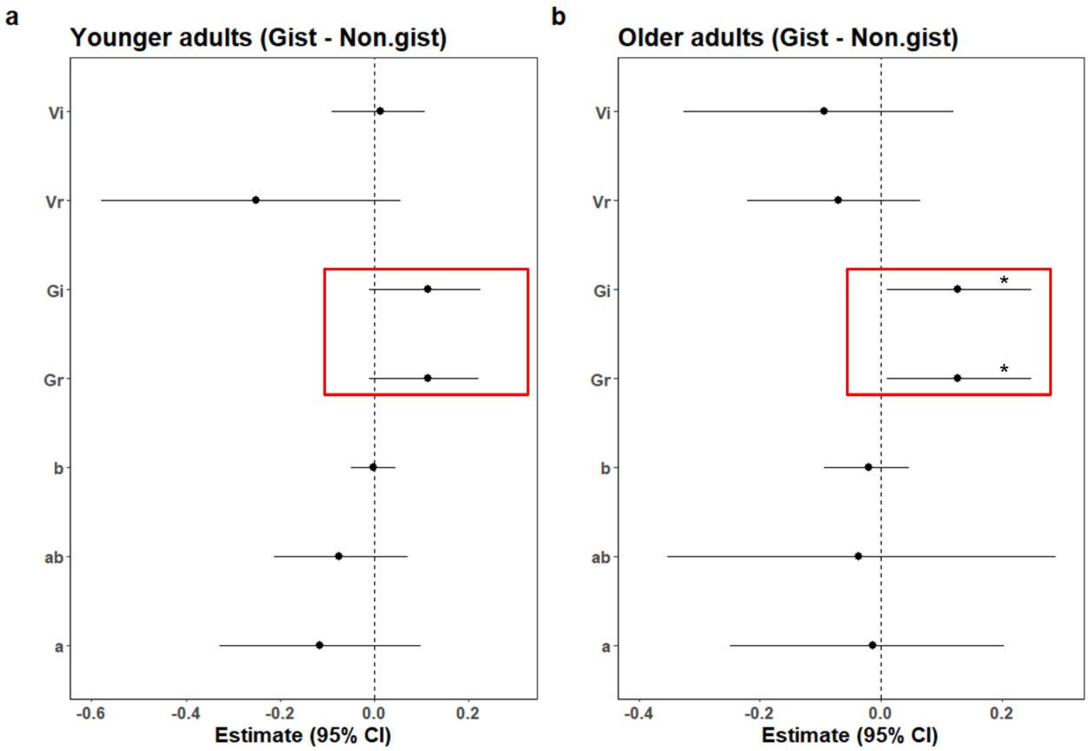

Figure 3. Forest plots show the differences in the interference conditions (gist minus non-gist) for each parameter in (a) younger adults and (b) older adults. Red boxes show the age-related difference in model parameters.

Inhibitory function. The Stroop results showed that the inhibitory function of older adults (M = 1.73; SD = 0.22) was significantly worse than that of younger adults (M = 1.87; SD = 0.12; t = 3.61, p < 0.001, Cohen's d = 0.82). Inhibitory function was positively correlated with memory task accuracy (r = 0.24, p = 0.03) and verbatim memory (r = 0.37, p < 0.001), whereas negatively correlated with R-I (r = -0.40, p < 0.001), but not with gist memory (r = 0.10, p = 0.39).

Mediation model. To examine the relationships between age groups, inhibitory function, R-I, and memory accuracy (ACC), a chain mediation model (Hayes & Rockwood, 2020) was run using PROCESS in SPSS (Model 6), controlling for years of education as a covariate. Table 1 presents the results of the chain mediation model, which includes Model 1, Model 2, Model 3, and the conditional indirect effects analysis. Model 1 tested the effects of age groups on inhibitory function, Model 2 tested the effects of age groups and inhibitory function on R-I, and Model 3 tested the effects of age groups, inhibitory function, and R-I on memory ACC. The conditional indirect effect analysis analyzed the effects of the mediation process.

Model 1 (F = 13.21, R^2 = 0.15, p < 0.001), Model 2 (F = 23.30, R^2 = 0.38, p < 0.001), and Model 3 (F = 28.15, R^2 = 0.53, p < 0.001) showed that age groups negatively correlated with memory ACC (β = -0.33, p = 0.002). In addition, age groups negatively predicted inhibitory function (β = -0.38, p < 0.001) and positively predicted R-I (β = 0.51, p < 0.001). Inhibitory function negatively predicted R-I (β = -0.21, p = 0.04) and had no relationship with memory ACC (β = -0.10, p = 0.25). R-I negatively predicted memory ACC (β = -0.53, p < 0.001). These results revealed a chain mediation model in which age groups affected memory ACC through a chain mediation pathway in which inhibitory function and R-I acted as mediators (see Figure 4). Detailed model results are provided in Table S2 in the Supplemental Material.

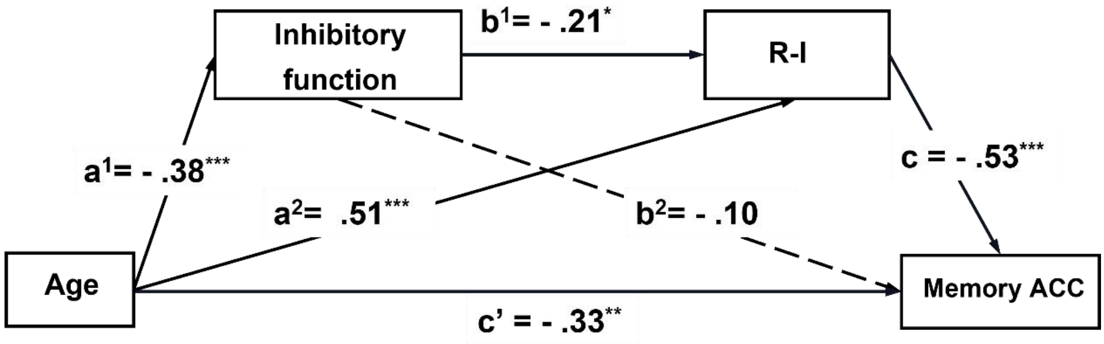

Figure 4. Chain mediation model. Age affected memory ACC through a chain mediation pathway in which inhibitory function and R-I acted as mediators. Age = younger (1) and older adult (2); IF = inhibitory function index from Stroop task; R-I = the proportion of "intact" response in related probes; ACC = the average accuracy of memory performance. *p < 0.05; **p < 0.01; ***p < 0.001.

Discussion

In Experiment 1, we explored (1) whether gist representation was more than non-gist interfere with associative memory in older adults, and (2) how inhibitory function affected the relationship between age and associative memory accuracy. We discovered that compared with non-gist representation, gist representation showed greater interfering effect on older adults. This interfering effect increased gist memory of older adults, which was supported by MPT model results. This also implied that gist representation required fewer cognitive resources for processing and integration into gist memory. Additionally, we also discovered that inhibitory function played a mediation role between age and associative memory accuracy. This was proved by a chain mediation model, which revealed that when age increased, inhibitory function declined, which resulted in more wrong response specific to gist condition (i.e., R-I) and eventually decreased their associative memory accuracy. Beside these two main findings, age-related differences in inhibitory function index from the Stroop task suggested inhibitory deficits in older adults. The interaction between age and interference condition on R-I suggested that older adults struggled more with gist-related interference. I.

Experiment 2

Experiment 1 elucidated the pathway by which inhibitory function deficits impair associative memory in older adults, and in Experiment 2 we further tested the possibility whether acute inhibitory training may ameliorate the detrimental effects of gist-related interfering on associative memory. Eye-movement techniques were used to capture the attentional distribution during the encoding phase of older adults' memories, which reflected the training effect of inhibitory function.

Method

***Participants*.** Sixty-six older adults were recruited to participate in Experiment 2. Participants were randomly assigned to either an acute inhibitory function training group or a control group. Data from three participants in the acute-training group and four participants in the control group were excluded due to eye tracking malfunction. As a result, 30 older adults (two males; age: M = 67.27, SD = 4.02; years of education: M = 10.23, SD = 2.62; MMSE: M = 28.93, SD = 1.17) in the acute-training group and 29 older adults (two males; age: M = 67.90, SD = 4.89; years of education: M = 11.21, SD = 2.66; MMSE: M = 28.93, SD = 0.92) in the control group were included in the subsequent statistical analyses. There were no significant differences in age, sex, years of education, or MMSE scores between the two groups (see Table S3 in the Supplemental Material).

***Procedure*.** Older adults in the acute-training group performed the Flanker task (Eriksen &

Eriksen, 1974; see the Supplementary Material for a Description of the Flanker task) prior to the memory task. Successful training was determined by an accuracy greater than 90%, otherwise additional rounds of the Flanker task were administered. After acute-training, older adults proceeded immediately to the memory task. Older adults in the control group did not perform the Flanker task, but completed the memory task directly.

Participants' eye movements were recorded throughout the memory task. The experiment was conducted in a standardized eye movement laboratory. Images were presented on a 20-inch monitor using E-Prime 2.0. The resolution of the laboratory computer screen was 1920 × 1080 pixels, with a refresh rate of 144 Hz. The distance between the screen and the subject's eyes was approximately 65 centimeters. The eye movement device used was an Eyelink 1000 (SR Research Ltd., Mississauga, ON, Canada) with a sampling rate of 500 Hz. All participants recorded information from their right eye and underwent a nine-point calibration procedure followed by a nine-point validation.

Data analyses

Eye movements. Three areas of interest (AOIs) were defined: figure AOI, target word AOI, and interfering word AOI. Fixations that were not in the AOI or were shorter than 100 milliseconds were excluded. Fixation duration (FD), fixation frequency (FF), and their proportions at each AOI (FD_P and FF_P) were extracted for subsequent analyses.

Structural Equation Modeling. Structural equation modeling (SEM; Kline, 2023) was used to examine the relationships among variables, including groups, eye movement parameters, R-I, and ACC, in order to explore the cognitive psychological pathway underlying the effect of acute inhibitory function training on associative memory. Specifically, a latent variable was constructed using four significant eye movement parameters in the interfering word AOI as proxies . The *lavaan* package in *R* 4.3.3 was used for these analyses (Rosseel, 2012). The $\chi 2$/df, comparative fit index (CFI), Tucker-Lewis index (TLI), standardized root mean square residual (SRMR), and root mean square error of approximation (RMSEA) were considered as model fit indices (Bentler, 1990). A value of $\chi 2$/df less than 2, a value of CFI and TLI greater than 0.90, and a value of SRMR and RMSEA less than 0.08 indicated a good model fit (Bentler, 1990).

Group differences between the acute-training and control groups were also tested for response proportion and MPT model parameters. However, group differences were not directly reflected in memory performance. These results are presented in the Supplementary Material.

Results

Eye movement results. Table 2 shows the values and differences of the eye movement parameters of the three AOIs in the acute-training and control groups respectively. For the interfering word AOI, there were significant group differences in FD (t = -2.30, p =. 025, df = 57, *Cohen's d* = -0.60), FD_P (t = -2.51, p =. 016, df = 57, *Cohen's d* = -0.66), FF (t =-3.14, p =. 003, df = 57, *Cohen's d* = -0.83), and FF_P (t = -2.90, p =. 006, df = 57, *Cohen's d* = -0.76), while there were no group differences in the target word AOI and figure AOI (*ps* >. 05). Figure 5 shows the eye movement hotspots of an exemplar stimulus in which the fixation duration of the interfering word AOI was significantly shorter in the acute-training group than in the control group.

Figure 5. Hotspot maps of older adults' fixation durations in the acute-training and control groups.

Table 2. Difference in the eye movement indices between the acute-training and control groups.

AOIs	Eye movement parameters	Acute-training *M* ± *SD*	Control *M* ± *SD*	*t*	*p*	Cohen's *d*
Interfering word AOI	Fixation duration	275.92±306.82	495.91±416.45	**-2.30**	**0.025**	-0.60
	Proportion of fixation duration	0.08 ± 0.08	0.15 ± 0.13	**-2.51**	**0.016**	-0.66
	Fixation frequency	1.16±1.06	2.42±1.90	**-3.14**	**0.003**	-0.83
	Proportion of fixation frequency	0.08±0.08	0.16±0.13	**-2.90**	**0.006**	-0.76
Target word AOI	Fixation duration	967.47 ± 642.54	861.87 ± 612.99	0.65	0.521	0.17
	Proportion of fixation duration	0.29 ± 0.18	0.25 ± 0.17	0.86	0.396	0.23
	Fixation frequency	3.96 ± 2.30	3.55 ± 2.06	0.72	0.473	0.19
	Proportion of fixation frequency	0.29 ± 0.17	0.25 ± 0.15	0.99	0.327	0.25
Figure AOI	Fixation duration	1991.44±760.12	1855.43±933.34	0.61	0.542	0.16
	Proportion of fixation duration	0.60 ± 0.21	0.56 ± 0.27	0.63	0.532	0.17
	Fixation frequency	8.05 ± 2.83	7.81 ± 3.61	0.29	0.771	0.07
	Proportion of fixation frequency	0.59 ± 0.20	0.54 ± 0.25	0.81	0.421	0.22

Note: AOI = area of interest.

Structural equation modeling. Four eye movement parameters (i.e., FD, FD_P, FIX, and FIX_P) constructed a latent variable "interference" reflecting older adult's fixations on the interfering word AOI, with standardized estimates of 0.96, 0.98, 0.99, and 0.99 respectively. Acute-training was negatively correlated with interference (β = -0.32, p = 0.01) and had no direct association with R-I (β = 0.18, p = 0.12) and memory ACC (β = -0.06, p = 0.49). Interference was positively correlated with R-I (β = 0.50, p < 0.001), but negatively correlated with ACC (β = -0.50, p < 0.001).

Figure 6 shows the path analyses, which revealed a chain mediation model in which acute-training affected memory ACC through a chain mediation pathway, with interference reflected by eye parameters and R-I acting as mediators (β = 0.07, p = 0.04). The model had a good fit (i.e., χ^2 /df = 1.25, CFI = 0.997, TLI = 0.994, SRMR = 0.011 and RMSEA = 0.065). In addition, a mediation model was also established in which acute-training affected memory ACC through affecting interference (β = 0.16, p = 0.02). Detailed model results are provided in Table S5 in the Supplemental Material.

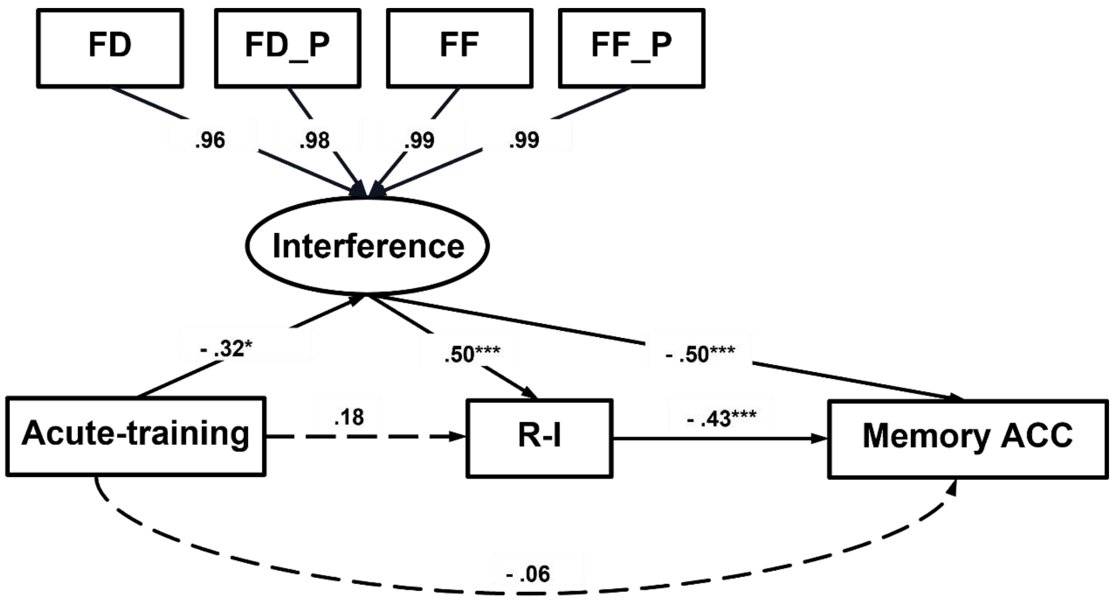

Figure 6. Structural equation modelling. Acute-training = the acute-training (2) and control group (1); Interference is eye movement parameters in the interfering word AOI. FD = fixation duration; FD_P = the proportion of fixation duration to total duration; FF = fixation frequency; FF_P = the proportion of fixation frequency to total frequency; R-I = the proportion of "intact" response in related probes; Memory ACC = the accuracy of associative memory. *p < 0.05. ***p < 0.001.

Discussion

In Experiment 2, we explored the possibility that acute-training inhibitory function could ameliorate the detrimental effects of inhibitory deficits in older adults. We found that while there were no direct differences in memory performance between the training and control groups, there was an encouraging possibility indicating that training inhibitory function could improve the impaired associative memory of older adults. This improvement was observed through a pathway revealed by eye-tracking technology. Specifically, acute training of older adults' inhibitory function diminished the processing of interfering information, which allowed older adults to make less inaccurate responses and eventually enhanced their accuracy in the associative memory task.

General Discussion

In the current study, we systematically explored the detrimental effect of inhibitory deficits on associative memory specifically due to increased interference during memory encoding in older adults, and explored the feasibility of acute-training of inhibitory function to ameliorate these inhibitory and associative memory deficits. We innovatively incorporated the inhibitory function paradigm into the associative memory paradigm to directly measure the effects of interfering information on associative memory, while no longer limiting ourselves to measuring a single memory performance (i.e., accuracy) as in previous studies, but additionally focusing on verbatim and gist memory based on fuzzy trace theory (Brainerd & Reyna, 1990, 2004; Reyna & Brainerd, 1995). We used eye-tracking technology to precisely capture the benefits of acute-training of inhibitory function, and to investigate the behavioral mechanisms responsible for older adult's associative memory improvement. By applying a complex and diverse range of analytical approaches, including MPT models, conditional process analysis and structural equation modelling, we arrived at the four main findings. Experiment 1 indicated that (1) gist representation more than non-gist interfered with associative memory in older adults, and (2) inhibitory function deficit mediated the relationship between age and associative memory decline. Experiment 2 revealed that (3) acute training inhibitory function has desirable feasibility in improving resistance to interference and then improving associative memory through a neuropsychological pathway in older adults, although (4) these benefits were not directly reflected in associative memory accuracy.

Gist representation more interferes with associative memory in older adults

Gist representation more than non-gist interfered with associative memory in older adults, which is consistent with hypothesis 1b (H1b). The MPT model showed that older adults showed better gist memory in the gist interfering word condition (i.e., gist representation) than in the non-gist interfering word condition, whereas both verbatim memory and gist memory were unaffected by these two conditions in younger adults. Immunity to interfering information in the younger cohort reflects the well-developed inhibitory function of younger people, which could effectively suppress the destructive effect of interfering with information invasion on memory. The inhibitory function index measured by the Stroop task also supported this conclusion, as the inhibitory function index of younger people was significantly higher than that of older people.

Older adults showed more gist memory than verbatim memory in the gist interfering word condition than in the non-gist interfering word condition. Note that we instructed participants to ignore the interfering word as much as possible, which would inevitably weaken the original influence of the interfering word. However, even after the interference effect was attenuated by the inhibitory function, the dissociation results showed that older adults' gist memory was affected, and their verbatim memory was not. The divergent patterns observed in the effects of interfering information on verbatim and gist memory in older adults suggest three points. One, impairments in inhibitory function in older adults result in their inability to suppress the influence of interfering information, a phenomenon supported by previous research (Hasher, 2015; Hasher & Zacks, 1988) and the inhibitory function index in the current study. Two, gist representation more than non-gist interfered with associative memory in older adults, which eventually enhanced their gist memory. This is likely to be attributed largely to the fact that gist representation is more automatic and easier to form, which requires fewer attentional resources to integrate into gist memory (Brainerd & Reyna, 1990, 2002; Greene & Naveh-Benjamin, 2023). In addition, older adults' over-reliance on gist memory (Greene & Naveh-Benjamin, 2023) aggravated the gist interfering effect. Three, verbatim and gist memory are components of different memory systems. This finding adds substantive evidence to the ongoing debate on the dichotomy between verbatim and gist memory. In this debate, fuzzy trace theory argues that verbatim and gist memory are distinct mnemonic entities (Brainerd & Reyna, 2004; Wolfe, 2021), whereas the gist macroprocessor framework posits that gist memory emerges because of verbatim memory processes (Kintsch, 1988; Kintsch & van Dijk, 1978; Perfetti, 2007).

Finally, it is important to note that an increase in gist memory is not always beneficial. According to the MPT model, when a gist representation is extracted, there is a probability that a participant will respond incorrectly, whereas when a verbatim representation is extracted, the participant will respond correctly. Therefore, compared to verbatim memory, gist memory is more robust with age but less accurate. Older adults' over-reliance on gist memory is a possible reason they make more inappropriate responses than younger adults.

Inhibitory deficits exacerbate associative memory deficits in older adults

Inhibitory function deficit mediated the relationship between age and associative memory decline, which is consistent with H2. Our results reveal an inhibition-related mechanism for the decline in associative memory in older adults. Specifically, older adults, due to impaired inhibitory function, make more gist-related associations of distractor information with the target, and respond incorrectly to the distractor information, thus leading to the decline of associative memory, which is reflected by the chain mediation between age group and accuracy in Experiment 1. As individuals age, they become increasingly susceptible to interference due to a decline in inhibitory function (Hasher, 2015; Hasher & Zacks, 1988). Consequently, they tend to create more false associations with interfering information during the memory encoding stage. This allows an increase in inaccurate responses during the retrieval of mnemonic associations, ultimately resulting in reduced associative memory accuracy.

Compared to the younger group, the older adult group had a lower rate of accuracy on the associative memory task. These also provide evidence for the associative difficulties hypothesis that older adults' associative memory decline is due to their impaired ability to make connections between episodic components (Naveh-Benjamin, 2000; Naveh-Benjamin et al., 2003, 2004; Old & Naveh-Benjamin, 2008). Older adults suffered more interference from gist-related information and made more inaccurate “intact” response in related probes based on their gist memory, which was revealed by an interaction effect of age groups and interference condition on R-I in Experiment 1. This indicated that older adults' overreliance on gist memory exacerbated the adverse effects of interference information, particularly gist-related interference, due to their inhibitory deficits and the less specificity of gist memory (Abadie et al., 2021; Greene & Naveh-Benjamin, 2020). This explains why older adults made more inaccurate responses in related probes and subsequently exhibited associative memory deficits.

Feasibility of inhibitory function training for associative memory improvement

Although acute inhibitory training did not significantly improve the associative memory of older adults in training group, which was inconsistent with H3, it has feasibility in reducing the effect of interfering information and then improving associative memory in older adults, which was consistent with H4. We found a desirable neuropsychologcial pathway by structural equation modelling that acute-training on inhibitory function reduced interference processing in the interfering areas in older adults, and then reduced their inaccurate response related to interference, thereby improving associative memory. These memory-related benefits provide convincing evidence for inhibitory functional training for associative memory improvement. Using eye-tracking technology, we explored the behavioral mechanisms underlying the effectiveness of inhibitory training by optimizing the distribution of attentional resources. According to the resource limitation theory (Kahneman, 1973), the cognitive system has limited resources, and when performing a task, individuals must efficiently allocate these limited cognitive resources, including attention, working memory capacity, and other cognitive abilities. One of the core concepts of this theory is competitive resource allocation, in which multiple tasks compete for limited cognitive resources. For older adults, there are a reduction in or an inequitable allocation of resources owing to cognitive aging. This manifests itself in older adults being more susceptible to performance decline in complex memory tasks than younger adults. The inhibitory function involves the inhibition of interfering information, which is particularly important in memory tasks because older adults are more susceptible to external distractions (Hasher, 2015; Hasher & Zacks, 1988). Inhibitory training modulates older adults' cognitive resources, allowing them to allocate their resources more efficiently and reduce their sensitivity to interfering information. This is supported by the current study's evidence that older adults in the acute-training group had less attentional resource allocation to interfering areas, and thus performed better on associative memory. Expressly, the feasibility of inhibitory training to improve associative memory is since such training can improve cognitive control and optimize older adults' use of cognitive resources, which is extremely important in the context of limited cognitive resources that decline with age.

Finally, we acknowledge that, as with other aging studies that use a cross-sectional design, we cannot claim that aging has caused these age changes, and we can only describe the age differences themselves because other factors may be responsible. At the same time, given that older adults in China generally have lower education levels than younger adults, the MPT model cannot control for the effect of education. However, we favored older adults in the experimental design in the hope of reducing these differences, which are not needed for experimental purposes. The benefits of acute inhibitory training were not reflected in memory performance, suggesting that the acute training effect is subtle and insufficient for an obvious associative memory improvement. Future direction is to explore the effect of long-term inhibitory intervention on associative memory decline based on our results of the acute-training effect.

In conclusion, due to impaired inhibitory function, gist representation more than non-gist interferes with associative memory in older adults, which made them form more inaccurate associations during memory encoding, ultimately leading to their associative memory deficits. In addition, it is feasible to train inhibitory functions to improve associative memory in older adults, and the behavioral mechanism behind this is meant to optimize the allocation of limited resources in older adults. Our study provides direction for clinical interventions targeting associative memory improvement.

Acknowledgements

We thank Nathaniel R. Greene and Moshe Naveh-Benjamin, who shared their analysis scripts on the Open Science Framework (OSF, https://osf.io/xk78c/).

Funding

This work was supported by the National Natural Science Foundation of China (32371109).

Reference

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

Aizpurua, A., & Koutstaal, W. (2010). Aging and flexible remembering: Contributions of conceptual span, fluid intelligence, and frontal functioning. *Psychology and Aging*, 25(1), 193–207. https://doi.org/10.1037/a0018198

Anderson, M. C., & Levy, B. J. (2007). Theoretical issues in inhibition: Insights from research on human memory. *In Inhibition in cognition*. (pp. 81–102). American Psychological Association. https://doi.org/10.1037/11587-005

Bentler, P. M. (1990). Fit Indexes, Lagrange Multipliers, Constraint Changes and Incomplete Data in Structural Models. *Multivariate Behavioral Research*, 25(2), 163 – 172. https://doi.org/10.1207/s15327906mbr2502_3

Bentler, P. M. (1990). Comparative fit indexes in structural models. *Psychological Bulletin*. 107:238–46. doi: 10.1037/0033-2909.107.2.238

Bomyea, J., & Amir, N. (2011). The Effect of an Executive Functioning Training Program on Working Memory Capacity and Intrusive Thoughts. *Cognitive Therapy and Research*, 35(6), 529–535. https://doi.org/10.1007/s10608-011-9369-8

Brainerd, C. J., & Reyna, V. F. (1990). Gist is the grist: Fuzzy-trace theory and the new intuitionism. *Developmental Review*, 10(1), 3–47. https://doi.org/10.1016/0273-2297(90)90003-M

Brainerd, C. J., & Reyna, V. F. (2002). Fuzzy-Trace Theory and False Memory. *Current Directions in Psychological Science*, 11(5), 164–169. https://doi.org/10.1111/1467-8721.00192

Brainerd, C. J., & Reyna, V. F. (2004). Fuzzy-trace theory and memory development. *Memory Development in the New Millennium*, 24(4), 396–439. https://doi.org/10.1016/j.dr.2004.08.005

Brainerd, C. J., & Reyna, V. F. (2015). Fuzzy-trace theory and lifespan cognitive development.

Theories of Development, 38, 89–121. https://doi.org/10.1016/j.dr.2015.07.006

Bürki, A., Elbuy, S., Madec, S., & Vasishth, S. (2020). What did we learn from forty years of research on semantic interference? A Bayesian meta-analysis. *Journal of Memory and Language*, 114, 104125. https://doi.org/10.1016/j.jml.2020.104125

Chiu, H.-L., Chan, P.-T., Kao, C.-C., Chu, H., Chang, P.-C., Hsiao, S.-T. S., Liu, D., Chang, W.-C., & Chou, K.-R. (2018). Effectiveness of executive function training on mental set shifting, working memory and inhibition in healthy older adults: A double-blind randomized controlled trials. *Journal of Advanced Nursing*, 74(5), 1099–1113. https://doi.org/10.1111/jan.13519

Craik, F. I. M. (2002). Levels of processing: Past, present… And future? *Memory*, 10(5–6), 305–318. https://doi.org/10.1080/09658210244000135

Craik, F. I. M., & Bialystok, E. (2006). Cognition through the lifespan: Mechanisms of change. *Trends in Cognitive Sciences*, 10(3), 131–138. https://doi.org/10.1016/j.tics.2006.01.007

Deese, J. (1959). On the prediction of occurrence of particular verbal intrusions in immediate recall. *Journal of Experimental Psychology*, 58(1), 17–22. https://doi.org/10.1037/h0046671

Diamond, A. (2013). Executive Functions. *Annual Review of Psychology*, 64(1), 135–168. https://doi.org/10.1146/annurev-psych-113011-143750

Eriksen, B. A., & Eriksen, C. W. (1974). Effects of noise letters upon the identification of a target letter in a nonsearch task. *Perception & Psychophysics*, 16(1), 143–149. https://doi.org/10.3758/BF03203267

Folstein, M. F., Folstein, S. E., & McHugh, P. R. (1975). “Mini-mental state”: A practical method for grading the cognitive state of patients for the clinician. *Journal of Psychiatric Research*, 12(3), 189–198.

Gallagher, M., & Koh, M. T. (2011). Episodic memory on the path to Alzheimer’s disease. *Neurobiology of Disease*, 21(6), 929–934. https://doi.org/10.1016/j.conb.2011.10.021

Greene, N. R., & Naveh-Benjamin, M. (2020). A Specificity Principle of Memory: Evidence From Aging and Associative Memory. *Psychological Science*, 31(3), 316–331. https://doi.org/10.1177/0956797620901760

Greene, N. R., & Naveh-Benjamin, M. (2022a). Effects of divided attention at encoding on specific and gist representations in working and long-term memory. *Journal of Memory and Language*, 126, 104340. https://doi.org/10.1016/j.jml.2022.104340

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. (2023a). 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. (2023b). The formation of specific and gist associative episodic memory representations during encoding: Effects of rate of presentation. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 49(7), 1099–1118. https://doi.org/10.1037/xlm0001173

Hasher, L. (2015). Inhibitory Deficit Hypothesis. *In The Encyclopedia of Adulthood and Aging* (pp. 1–5). https://doi.org/10.1002/9781118521373.wbeaa259

Hasher, L., & Zacks, R. T. (1988). Working Memory, Comprehension, and Aging: A Review and a New View. In G. H. Bower (Ed.), *Psychology of Learning and Motivation* (Vol. 22, pp. 193–225). Academic Press. https://doi.org/10.1016/S0079-7421(08)60041-9

Hornberger, M., & Piguet, O. (2012). Episodic memory in frontotemporal dementia: A critical review. *Brain*, 135(3), 678–692. https://doi.org/10.1093/brain/aws011

Ji, Y., Wang, J., Chen, T., Du, X., & Zhan, Y. (2016). Plasticity of inhibitory processes and associated far-transfer effects in older adults. *Psychology and Aging*, 31(5), 415–429.

https://doi.org/10.1037/pag0000102
Kahneman, D. (1973). Attention and effort (Vol. 1063). Citeseer.
Kintsch, W. (1988). The role of knowledge in discourse comprehension: A construction-integration model. *Psychological Review*, 95(2), 163–182. https://doi.org/10.1037/0033-295X.95.2.163
Kintsch, W., & van Dijk, T. A. (1978). Toward a model of text comprehension and production. *Psychological Review*, 85(5), 363–394. https://doi.org/10.1037/0033-295X.85.5.363
Kline, R. B. (2023). Principles and Practice of Structural Equation Modeling. *Guilford Publications*. https://books.google.com/books?id=t2CvEAAAQBAJ
Konkle, T., Brady, T. F., Alvarez, G. A., & Oliva, A. (2010). Scene memory is more detailed than you think: The role of categories in visual long-term memory. *Psychological Science*, 21(11), 1551–1556.
Lindenberger, U. (2014). Human cognitive aging: Corriger la fortune? *Science*, 346(6209), 572–578. https://doi.org/10.1126/science.1254403
Lustig, C., Hasher, L., & Zacks, R. T. (2007). Inhibitory deficit theory: Recent developments in a “new view.” In *Inhibition in cognition*. (pp. 145–162). American Psychological Association. https://doi.org/10.1037/11587-008
Maraver, M. J., Bajo, M. T., & Gomez-Ariza, C. J. (2016). Training on Working Memory and Inhibitory Control in Young Adults. *Frontiers in Human Neuroscience*, 10. https://www.frontiersin.org/articles/10.3389/fnhum.2016.00588
Naveh-Benjamin, M. (2000). Adult age differences in memory performance: Tests of an associative deficit hypothesis. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 26(5), 1170–1187. https://doi.org/10.1037/0278-7393.26.5.1170
Naveh-Benjamin, M., Guez, J., Kilb, A., & Reedy, S. (2004). The Associative Memory Deficit of Older Adults: Further Support Using Face-Name Associations. *Psychology and Aging*, 19(3), 541–546. https://doi.org/10.1037/0882-7974.19.3.541
Naveh-Benjamin, M., Hussain, Z., Guez, J., & Bar-On, M. (2003). Adult age differences in episodic memory: Further support for an associative-deficit hypothesis. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 29(5), 826–837. https://doi.org/10.1037/0278-7393.29.5.826
Nguyen, L., Murphy, K., & Andrews, G. (2019). Immediate and long-term efficacy of executive functions cognitive training in older adults: A systematic review and meta-analysis. *Psychological Bulletin*, 145(7), 698–733. https://doi.org/10.1037/bul0000196
Nieznański, M., & Obidziński, M. (2019). Verbatim and gist memory and individual differences in inhibition, sustained attention, and working memory capacity. *Journal of Cognitive Psychology*, 31(1), 16–33. https://doi.org/10.1080/20445911.2019.1567517
Perfetti, C. (2007). Reading Ability: Lexical Quality to Comprehension. *Scientific Studies of Reading*, 11(4), 357–383. https://doi.org/10.1080/10888430701530730
Reyna, V. F. (1995). 2—Interference effects in memory and reasoning: A fuzzy-trace theory analysis. In F. N. Dempster, C. J. Brainerd, & C. J. Brainerd (Eds.), *Interference and Inhibition in Cognition* (pp. 29–59). Academic Press. https://doi.org/10.1016/B978-012208930-5/50003-9
Reyna, V. F., & Brainerd, C. J. (1995). Fuzzy-trace theory: An interim synthesis. *Special Issue: Fuzzy-Trace Theory*, 7(1), 1–75. https://doi.org/10.1016/1041-6080(95)90031-4
Reyna, V. F., & Mills, B. A. (2007). Interference processes in fuzzy-trace theory: Aging, Alzheimer’s disease, and development. In *Inhibition in cognition.* (pp. 185–210). American Psychological Association. https://doi.org/10.1037/11587-010
Roediger, H. L., & McDermott, K. B. (1995). Creating false memories: Remembering words not presented in lists. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 21(4), 803–814. https://doi.org/10.1037/0278-7393.21.4.803
Rosseel, Y. (2012). lavaan: An R Package for Structural Equation Modeling. *Journal of Statistical*

Software, 48(2), 1–36. https://doi.org/10.18637/jss.v048.i02
Sander, M. C., Fandakova, Y., & Werkle-Bergner, M. (2021). *Effects of age differences in memory formation on neural mechanisms of consolidation and retrieval*. Special Issue: Myelin Edited by Gonçalo Castelo-Branco and Roman Chrast / Special Issue: Aging in the Nervous System Edited by Mara Mather, 116, 135–145. https://doi.org/10.1016/j.semcdb.2021.02.005
Schneider, W., Eschman, A., & Zuccolotto, A. (2012). *E-Prime 2.0 reference guide manual*. Pittsburgh, PA: Psychology Software Tools.
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.
Stroop, J. R. (1935). Studies of interference in serial verbal reactions. *Journal of Experimental Psychology*, 18(6), 643–662. https://doi.org/10.1037/h0054651
Surprenant, A. M., & Neath, I. (2009). *Principles of memory (1st Edition)*. Psychology Press.
Tulving, E. (1984). Précis of Elements of episodic memory. *Behavioral and Brain Sciences*, 7(2), 223–238. Cambridge Core. https://doi.org/10.1017/S0140525X0004440X
Wolfe, C. R. (2021). Fuzzy-trace theory and the battle for the gist in the public mind. *Journal of Applied Research in Memory and Cognition*, 10(4), 527–531. https://doi.org/10.1016/j.jarmac.2021.10.004
Xu, J.-J., Lin, G.-J., Fang, F., & Yu, J. (2023). Relationship between self-reported sleep and cognitive function: A specification curve analysis. *Cognitive Processing*, 24(3), 451–462. https://doi.org/10.1007/s10339-023-01133-5
Zhao, X., Chen, L., & Maes, J. H. R. (2018). Training and transfer effects of response inhibition training in children and adults. *Developmental Science*, 21(1), e12511. https://doi.org/10.1111/desc.12511