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Age Differences in the Reactivity Effect of Judgments of Learning on Recognition Memory

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Recent studies established that engaging metacognitive monitoring via making judgments of learning (JOLs) can directly enhance young adults' recognition memory, a phenomenon termed the *reactivity effect* of JOLs. The present study explored the reactive influence of making JOLs on older adults' recognition memory and probed the potential age-related differences in this effect. In three experiments, participants were instructed to study four lists of words, with two lists studied with concurrent JOLs and the other two without, followed by a recognition test. The results provided strong evidence that making JOLs improves older adults' recognition performance (Experiments 1–3) through enhancing both recollection- and familiarity-based recognition (Experiment 3). But the positive reactivity effect on recognition memory for older adults was weaker than that for young adults (Experiments 2 and 3). To elucidate potential mechanisms underlying age-related differences in the reactivity effect, the present study also measured participants' learning engagement and cognitive abilities. The model results substantiated the mediating role of learning engagement, supporting the enhanced learning engagement theory, rather than the dual-task hypothesis, as an account for the reactivity effect on recognition memory.

Public Significance Statement

The present study documents that soliciting judgments of learning can enhance older adults' recognition memory through enhancing both recollection and familiarity processes, but the enhancement effect for older adults is relatively weaker than that for young adults. The reduced benefit of making judgments of learning for older adults should be attributed to their higher learning engagement rather than any impact of cognitive ability. Practical implications of these positive effects and the underlying mechanisms should be taken into account when formulating programs to tackle age-related memory deterioration.

Keywords: judgments of learning, reactivity effect, aging, recognition memory

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The deidentified data on which the study conclusions are based, the analytical code necessary to reproduce analyses, and the materials used in this study are publicly available at the Open Science Framework (https://osf.io/v7fye/). The authors declare that the ideas and data appearing in the article have not been previously disseminated (e.g., at a conference or meeting, posted on a listserv, shared on a website).

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continued

Metacognition refers to the processes of monitoring and controlling cognitive activities (Nelson & Narens, 1990). Many studies have employed judgments of learning (JOLs; i.e., prospective estimations about the likelihood of remembering a studied item on a future memory test) to assess individuals' ability in monitoring their learning or memory status (e.g., Hu et al., 2021; M. G. Rhodes & Castel, 2008; Yang et al., 2018). Previous studies have established a close connection between learners' control of learning behaviors (e.g., restudy choices, study time allocation) and their JOLs (i.e., metacognitive monitoring of learning status), highlighting the importance of accurate JOLs for efficient learning (Thiede et al., 2003; Tullis et al., 2013; Yang et al., 2017). Interestingly, a growing body of research has shown that the act of making JOLs can directly impact the memory processes being monitored, a phenomenon known as the "reactivity effect of JOLs" (for a review, see Double et al., 2018).

The past decade has witnessed a burgeoning of research on JOL reactivity. Numerous studies with young adults as participants have documented that making JOLs can significantly boost their memory for certain materials (e.g., related word pairs, word lists, and visual images), leading to positive reactivity effects (e.g., Li et al., 2023; Shi et al., 2023; Soderstrom et al., 2015; Witherby & Tauber, 2017; Zheng et al., 2024). Nevertheless, little research has been conducted to explore the reactive influence of JOLs on memory performance in older adults (Tauber & Witherby, 2019). Given that making JOLs has the potential to be a simple and effective mnemonic technique, exploring whether the positive reactivity effect generalizes to older adults is of great practical importance. Examining age-related differences can also contribute to our understanding of the mechanisms underlying JOL reactivity. The practical and theoretical importance jointly motivate the present study to examine the JOL reactivity effect in older adults and age-related differences in this effect.

Below, we first review previous findings regarding the JOL reactivity effect and its potential underlying mechanisms, then highlight the practical and theoretical importance of exploring age-related differences in JOL reactivity, and finally provide an overview of the present study.

JOL Reactivity and Putative Mechanisms

The majority of previous studies have recruited young adults as participants to examine whether soliciting item-by-item JOLs can reactively alter their memory. Findings suggest that making JOLs generally enhances young adults' memory performance for certain types of materials (Double et al., 2018). As an illustration, Soderstrom et al. (2015) instructed two groups of young participants to study a list of related (e.g., *loaf-bread*) and unrelated (e.g., *sack-flag*) word pairs. The JOL group studied each word pair for 8 s and provided a JOL (i.e., estimating the likelihood of recalling the target word associated with the cue on a later test) while studying each word pair. In contrast, the no-JOL group studied each word pair for the same duration without making JOLs. After a 3-min retention interval, participants completed a cued recall test. The results showed that the JOL group recalled significantly more related word pairs than the no-JOL group, with no significant difference observed in recall of unrelated word pairs. Numerous studies have consistently demonstrated that making JOLs has a positive reactivity effect on memory for related word pairs (e.g., Halamish & Undorf, 2023; Janes et al., 2018; Li et al., 2022, 2023; Maxwell & Huff, 2022, 2024; Myers et al., 2020; Rivers et al., 2021, 2023; Zhao et al., 2025), and this effect remains robust even after long delays (at least 48 hr; Witherby & Tauber, 2017). However, making JOLs typically has no effect (Double et al., 2018; Maxwell & Huff, 2022), or sometimes even has a negative effect on memory for unrelated word pairs (Mitchum et al., 2016; Undorf et al., 2024).

Apart from the JOL reactivity effect on associative learning, many studies have established that making JOLs can substantially facilitate recognition memory for word lists (e.g., Li et al., 2022, 2023; Myers et al., 2020; Tekin & Roediger, 2020; Zhao et al., 2022; Zheng et al., 2024). For instance, Li et al. (2022) instructed young participants to study four lists of words, with two lists studied with item-by-item JOLs and the other two without. After a 5-min retention interval, participants completed an old/new recognition test. The results showed that participants recognized more JOL words than no-JOL ones, indicating a positive reactivity effect on recognition memory for young adults. Furthermore, other studies have shown that this positive JOL reactivity effect is long-lasting (Zheng et al., 2024) and generalizable to nonverbal materials (Shi et al., 2023) and elementary school children (Zhao et al., 2022).

As JOL reactivity is a multifaced phenomenon, various theories have been proposed to account for its effects on memory for different types of materials (Janes et al., 2018; Zhao et al., 2023). The *cue-strengthening theory*, put forth by Soderstrom et al. (2015), specifically addresses the JOL reactivity effect on associative learning of word pairs. This theory posits that participants have to search for inferential cues to make reasonable JOLs (Koriat, 1997), meaning that in the context of word pair learning, they utilize the intrinsic relatedness of word pairs to form JOLs. Therefore, the act of making JOLs strengthens relatedness cues (i.e., existing relational information between the cue and the target) for related word pairs, thereby enhancing cued recall of related word pairs. In contrast, for unrelated word pairs that lack preexisting cue–target relations, the reactive influence of making JOLs on cued recall is minimal. Many studies have provided evidence supporting this theory. For instance, the positive reactivity effect has been observed on word pairs with various types of semantic relations (e.g., forward, symmetrical, and backward related pairs, as well as category-cued pairs), but not on word pairs lacking a semantic relationship (e.g., Maxwell & Huff, 2022; Rivers et al., 2023).

A recently proposed theory, the *enhanced learning engagement (ELE) theory* (Shi et al., 2023; Zhao et al., 2022), accounts for the overall positive reactivity effect of JOLs observed in various studies. It hypothesizes that learners typically experience a decline in attention and an increase in mind-wandering during prolonged

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learning tasks (Risko et al., 2012; Szpunar et al., 2013). When participants are required to provide item-by-item JOLs, they have to closely study and analyze each study item to identify inference cues to make reasonable JOLs. This process, in turn, focuses their attention on the current learning task, thereby producing superior learning outcomes. Since word lists or visual materials lack the inherent associations present in word pairs, the ELE theory can effectively explain the positive JOL reactivity effect on recognition memory for these materials (for a detailed discussion, see below or refer to Zheng et al., 2024). This theory was empirically tested in a study by Shi et al. (2023), which found that the frequency of mind-wandering was lower in the JOL condition than in the no-JOL condition and that the difference in mind-wandering rates significantly mediated the positive reactivity effect on recognition memory.

An alternative hypothesis, the *dual-task hypothesis* (Mitchum et al., 2016), seems to work in conjunction with the aforementioned theories to explain why, at times, nonreactivity or even negative reactivity effect occurs. This hypothesis posits that the requirement to make JOLs may function as a secondary task that borrows limited cognitive resources from the primary learning task. Frequent switching between the learning task and the JOL monitoring task results in dual-task costs, which can hinder positive reactivity (such as enhanced cue–target relation or learning engagement) and may even lead to negative reactivity, especially in challenging learning tasks like studying unrelated word pairs. These theoretical inferences are reasonable (Mitchum et al., 2016; Witherby et al., 2023). Empirical evidence from Zhao et al. (2025) supports this hypothesis, as they found that participants' working memory capacity positively predicted the magnitude of the JOL reactivity effect.

Age-Related Differences in JOL Reactivity

Given the overall positive impact of JOLs on memory performance, many researchers proposed that making JOLs may be used as an easy-to-implement intervention in educational settings (Ariel et al., 2021; Davis & Chan, 2023; Lee & Ha, 2019; Soderstrom et al., 2015; Witherby & Tauber, 2017). However, before recommending this practice, it is essential to investigate which groups of people can benefit from it and which cannot (Zhao et al., 2025). Older adults, as vital members of society, have an urgent need for simple and effective memory enhancement techniques. Nonetheless, the current exploration of whether and how making JOLs reactively impacts memory performance for older adults remains insufficient (Murphy et al., 2024; Tauber & Witherby, 2019).

To our knowledge, two recent studies have explored the reactive influences of making JOLs on older adults' memory using a paired-associate learning paradigm. In Tauber and Witherby (2019), older and young participants were instructed to study a list of related word pairs, with half of the participants in each age group providing concurrent JOLs and the other half not. The no-JOL group studied each word pair for a total of 10 s, while the JOL group studied each pair for the same duration but was prompted to make a JOL during the final 5 s of exposure. The results showed no detectable difference in cued recall between the JOL and no-JOL groups among older participants. In other words, the act of making JOLs does not affect older adults' memory for related word pairs, in contrast to the robust positive reactivity effect observed in young adults (Tauber & Witherby, 2019). Furthermore, Murphy et al. (2024) found that making JOLs seems to have a negative effect on older adults' memory for unrelated word pairs, while young adults do not experience any impairment effect under the same condition.

From a practical perspective, it is important to comprehensively examine the reactive influence of JOLs on various types of memory tasks in older adults. The results of the two studies mentioned above provide initial insights into the JOL reactivity effect on older adults' cued recall. However, it remains an open question regarding whether making JOLs affects older adults' recognition memory (Shepard, 1967; Yonelinas, 2002). On one hand, as previously noted, the underlying mechanisms of JOL reactivity may differ depending on the type of information being studied. There are inherent differences between learning word pairs and learning individual words (cf. the cue-strengthening theory and the ELE theory). It has been well-established that older adults tend to perform better on recognition tasks than on recall tasks (Craik, 2020; Craik & McDowd, 1987; Whiting et al., 1997), suggesting that the challenges of these two tasks differ for older adults (cf. the dual-task hypothesis). Therefore, the findings regarding the JOL reactivity effect on older adults' memory for word pairs cannot be directly extrapolated to the effect on older adults' memory for word lists.

On the other hand, numerous cognitive and neuropsychological studies have demonstrated that recognition memory involves two distinct processes (or components): recollection and familiarity (Eichenbaum et al., 2007; Yonelinas, 2002; Yonelinas et al., 2010). Specifically, individuals can identify a stimulus as previously encountered (i.e., old) based either on recollection of specific contextual details about previous events or on assessment of stimulus familiarity without such contextual details. Recently, Zheng et al. (2024) utilized a remember/know (R/K) procedure during the test phase and found that making JOLs facilitated young participants' recognition memory through enhancing both recollection and familiarity. Enhancing either component of recollection or familiarity would also benefit recognition performance in older adults. Therefore, the two primary aims of this study are to examine whether soliciting JOLs can boost older adults' relatively preserved recognition and, if so, which component (i.e., recollection, familiarity, or a combination of both) of their recognition memory is susceptible to JOL reactivity.

From a theoretical perspective, exploring age-related differences in the JOL reactivity effect between older and young adults can further deepen our understanding of the underlying mechanisms. According to the ELE theory (Shi et al., 2023), the positive reactivity effect in older adults should be weaker than that in young adults. Many studies on mind-wandering have shown an age-related decrease in its frequency (for a meta-analysis, see Jordão et al., 2019). Older adults consistently exhibit a reduction in mind-wandering compared to young adults, a robust finding observed in both laboratory settings (Krawietz et al., 2012) and daily life (Maillet et al., 2018). Hence, the higher level of learning engagement in older adults may constrain the space for making JOLs to enhance their learning engagement, resulting in a smaller positive reactivity effect on learning outcomes (e.g., recognition performance) for older than for young adults.

The cue-strengthening theory (Soderstrom et al., 2015) emphasizes the reinforcement of preexisting relational information (i.e., enhancing memory of related word pairs rather than unrelated ones). As suggested by research on memory aging, older adults experience a processing deficit in associative learning (Craik & Rose, 2012; Naveh-Benjamin et al., 2007). Therefore, when learning related word pairs, their impaired associative processing abilities may create a hurdle in deriving benefits from the relational information strengthened by making JOLs (Tauber & Witherby, 2019).

The dual-task hypothesis (Mitchum et al., 2016) predicts a similar age-related decrease in JOL reactivity. Considering that older adults' cognitive abilities (e.g., processing speed, working memory capacity) typically decline as a function of aging (Baltes & Lindenberger, 1997; Nettelbeck & Burns, 2010), simultaneously performing the learning task and the JOL monitoring task should be more challenging for older than for young adults. Consequently, dual-task costs induced by the requirement of making concurrent JOLs should be greater for older than for young adults, leading to a weaker positive reactivity effect for older adults. Moreover, in difficult learning tasks (e.g., learning unrelated word pairs with a time pressure), making concurrent JOLs may negatively impact older adults' overall learning performance.

The previous two studies have identified age differences in the JOL reactivity effect on cued recall. They showed that making JOLs enhances memory for related word pairs in young but not in older adults (Tauber & Witherby, 2019) and impairs memory for unrelated word pairs in older but not in young adults (Murphy et al., 2024). These patterns of results are consistent with the theoretical inferences discussed above. Factors such as reduced learning engagement enhancement, failures in cue-strengthening, and increased dual-task costs may collectively contribute to these findings, although there is currently no direct evidence to identify the primary causes. Returning to the context of learning word lists, it remains unclear whether there are differences in the JOL reactivity effect on recognition memory between older and young adults. Additionally, it is uncertain whether the ELE theory and/or the dual-task hypothesis can account for potential age differences, as both theories currently have not received sufficient empirical tests (Zhao et al., 2025).

Overall, the ELE theory predicts a positive reactivity effect on older adults' recognition memory for word lists, and both the ELE theory and the dual-task hypothesis predict an age-related decline in the magnitude of this effect. As suggested by Zheng et al. (2024), when learning word lists, enhanced learning engagement may improve item recollection by increasing encoding distinctiveness and directly enhancing item familiarity. Specifically, the act of making JOLs may increase item distinctiveness (e.g., information about whether one had made a JOL for a given item, information activated while searching for mnemonic cues to make JOLs), leading to better recollection-based recognition. And the enhanced learning engagement induced by the requirement of making JOLs may directly contribute to the overall memory strength of JOL items, ultimately enhancing familiarity-based recognition.

Empirical evidence indicates that although there are typically nonzero age differences in recognition memory (for meta-analyses, see Fraundorf et al., 2019; S. Rhodes et al., 2019), older adults demonstrate item recognition comparable to that of young adults in many instances (Algarabel et al., 2009; Ratcliff et al., 2011). Prior research has shown that several encoding manipulations (e.g., production, generation), which highlight attention to study information or its distinctiveness characteristics, can enhance older adults' recollection of studied information (e.g., Geraci et al., 2009; Leshikar et al., 2015; Lin & MacLeod, 2012; Troyer et al., 2006). For instance, older participants recalled more words that were previously read aloud than those read silently, a phenomenon known as the production effect (Lin & MacLeod, 2012). On the other hand, previous studies also observed that normal aging diminishes recollection while having a smaller impairment effect on familiarity (Koen & Yonelinas, 2016; Yonelinas, 2002). A relatively intact familiarity-based recognition ability in older adults may support them to benefit from encoding manipulations that can facilitate the corresponding components. Based on theoretical and empirical evidence, we speculate that making JOLs can enhance older adults' recognition memory through facilitating their recollection-based recognition, familiarity-based recognition, or a combination of both.

Overview of the Present Study

As discussed above, although the positive reactivity effect on recognition memory has been well-established in young adults, it remains unclear (a) whether the act of making JOLs can enhance older adults' recognition memory and (b) whether this potential positive reactivity effect stems from boosting different components (i.e., recollection or familiarity) of older adults' recognition memory. Additionally, it is unknown (c) whether the magnitude of the reactivity effect on recognition memory differs between older and young adults and (d) which mechanisms underlie such age-related differences. The present study was designed to address these important questions.

Experiment 1 first examined the reactive influence of JOLs on older adults' recognition memory for word lists, where two lists of words were studied with concurrent JOLs and the other lists without. To foreshadow, Experiment 1 observed a positive reactivity effect on older participants' recognition memory. Experiment 2 recruited both young and older participants to explore age-related differences in the magnitude of the reactivity effect on recognition memory. Besides reaffirming the main findings of Experiments 1 and 2, Experiment 3 employed the R/K procedure to further explore the roles of recollection and familiarity in the reactivity effect on older adults' recognition memory.

Finally, to clarify the mechanisms underlying age-related differences in the reactivity effect, data from all three experiments were integrated, and a structural equation model (SEM) was constructed. This model aimed to examine whether learning engagement and/or cognitive ability mediates age-related differences in the reactivity effect on recognition memory. Such a model allows us to test the ELE theory and the dual-task hypothesis (see below for details). Throughout all experiments in this study, various questionnaires were used to measure all participants' learning engagement, such as mind-wandering tendency, and a cognitive assessment battery was used to evaluate their cognitive abilities, such as processing speed.

Experiment 1

Experiment 1 was conducted to investigate whether making item-by-item JOLs can reactively improve older adults' recognition memory for word lists.

Method

Design and Participants

The experiment involved a within-subjects design (study method: JOL vs. no-JOL). According to the results of a pilot study ($n = 6$;

Cohen's $d = 0.92$), we estimated that at least 12 participants were required to observe a significant (two-tailed $\alpha = .05$) reactivity effect at 0.80 power. To be more conservative, we decided to increase the sample size to 30. A total of 32 older adults were recruited from the local community. Data of three participants were excluded for the following reasons. One failed to complete the experiment due to computer failure, one did not achieve a minimum score of 25 on the Mini-Mental State Examination (MMSE; Folstein et al., 1975), and the other one provided the "old" response to all test items in the recognition test. Thus, the final sample consisted of 29 older participants (age range 66–74, $M_{\text{age}} = 68.93$, $SD = 2.58$; 21 female). Descriptive statistics of demographic characteristics, questionnaire assessments, and cognitive functioning are listed in Table 1.

Older participants completed a demographic questionnaire (brief health histories) to allow researchers to check inclusion criteria before they were invited to attend. For all experiments reported here, older participants reported no history of major cognitive impairment or psychiatric disorders, did not take any memory-enhancing medications or receive memory skills training, and had normal or corrected-to-normal vision. All participants provided written informed consent before taking part in the experiment and were tested individually. For compensation, older participants received a reward of 60 renminbi.

This study was approved by the Ethics Committee of Beijing Normal University Faculty of Psychology (No. 202201040001; Study on Learning, Memory, and Metacognition in Older Adults). Data collection took place in Beijing during 2022.

Measures and Procedure

Participants first performed the JOL reactivity task on the computer in a quiet laboratory room. Next, they completed postexperiment questionnaires in a paper-and-pen format. Finally, they engaged in cognitive tests (see details in the Supplemental Materials). The assessments were administered in the order described below.

JOL Reactivity Task. The materials and procedure were taken from Zheng et al. (2024). The study materials consisted of 330 two-character Chinese words (Cai & Brysbaert, 2010), with word frequency ranging from 1.4 to 20.45 per million ($M_{\text{frequency}} = 9.73$, $SD = 5.45$) and stroke counts ranging from 5 to 35 ($M_{\text{stroke}} = 17.31$, $SD = 4.98$). Ten words were used for practice, and the remaining 320 words were used for the formal experiment. To avoid any item-selection effects, for each participant, the computer randomly selected 160 words to be presented during the study phase, and these words also served as "old" words in the recognition test, with the other 160 words serving as "new" words in the recognition test. The 160 to-be-studied words were randomly divided into four lists, with two lists randomly assigned to the JOL condition and the other two assigned to the no-JOL condition. The list sequence (i.e., JOL vs. no-JOL) and the presentation sequence of words in each list were randomized for each participant.

Participants were informed that they would study four lists of words, each containing 40 words, in preparation for a later memory test. They were also told that they would need to make memory predictions for two lists (i.e., JOL condition), while no such predictions were required for the other two lists (i.e., no-JOL condition). Importantly, they were explicitly informed that all the words presented during the study phase would be eventually tested, and therefore, they needed to exert equal effort in memorizing all words, regardless of whether or not those words needed to be subjected to memory predictions.

Before the formal experiment, participants completed a practice task to familiarize themselves with the task requirements. Following practice, participants were asked if they understood the task requirements. If not, the experimenter reexplained the task requirements and participants repracticed the task. This cycle continued

Table 1
Characteristics of Participants in Experiments 1–3

Measure	Experiment 1	Experiment 2			Experiment 3		
	Old (n = 29)	Old (n = 32)	Young (n = 30)	t	Old (n = 44)	Young (n = 45)	t
Age (years)	68.93 (2.58)	67.88 (3.11)	22.50 (2.24)	−65.56***	68.82 (2.87)	21.78 (1.95)	−90.55***
Education (years)	11.55 (1.74)	10.94 (1.85)	16.10 (2.06)	10.41***	11.82 (1.86)	15.24 (1.87)	8.66***
Physical health	3.93 (0.59)	3.56 (0.76)	3.97 (0.56)	2.34*	3.75 (0.62)	3.82 (0.72)	0.51
Mental health	4.03 (0.57)	3.81 (0.78)	3.83 (0.70)	0.11	4.18 (0.50)	3.89 (0.68)	−2.32*
Task interestingness	5.90 (1.11)	5.97 (1.03)	4.60 (0.62)	−6.28***	6.18 (0.82)	4.69 (1.15)	−7.08***
Task difficulty	4.38 (1.32)	4.06 (1.34)	4.17 (1.29)	0.31	3.77 (1.66)	3.60 (1.47)	−0.52
Task focus	6.24 (0.99)	6.34 (0.87)	5.53 (1.11)	−3.22**	6.61 (0.75)	5.82 (0.83)	−4.69***
Task effort	6.17 (0.93)	6.47 (0.72)	5.37 (1.22)	−4.38***	6.34 (0.94)	5.62 (0.78)	−3.94***
Task motivation	6.66 (0.55)	6.47 (0.88)	5.70 (0.88)	−3.45***	6.71 (0.55)	5.76 (0.88)	−6.06***
Mind-wandering	2.62 (0.81)	2.54 (0.91)	3.18 (0.61)	3.17**	2.21 (0.72)	3.43 (0.80)	7.55***
MMSE	28.14 (1.06)	27.44 (1.19)	28.97 (1.00)	5.46***	27.75 (1.40)	29.00 (0.95)	4.93***
Processing speed	23.38 (6.37)	22.72 (6.50)	39.77 (5.96)	10.74***	22.14 (5.61)	40.67 (6.19)	14.79***
Working memory	5.00 (1.65)	4.06 (1.08)	6.63 (1.92)	6.56***	4.59 (1.17)	7.22 (1.69)	8.53***
Verbal fluency	16.08 (3.20)	15.96 (3.70)	18.69 (3.75)	2.89**	16.00 (3.22)	18.93 (4.15)	3.71***

Note. Means, standard deviations (in parentheses), and independent t test results of the differences between older and young groups; self-rated health (i.e., physical and mental) is rated on a 5-point scale (1 = *very poor*; 2 = *poor*; 3 = *average*; 4 = *good*; 5 = *very good*; Jin et al., 2023); self-reported task interestingness, difficulty, focus, effort, and motivation are made on a scale ranging from 1 (*very little*) to 7 (*very much*); mind-wandering was reported on a 1–6 scale; total scores of MMSE, processing speed, and working memory are 30, 48, and 10, respectively; verbal fluency is the average score of the test. MMSE = Mini-Mental State Examination.
* $p < .05$. ** $p < .01$. *** $p < .001$.

until a given participant fully understood the task requirements. Then, the formal experiment began.

In the study phase, the computer informed participants whether they would need to make memory predictions for the upcoming list of words. In a no-JOL list, 40 words were presented one at a time, with each word displayed for 6 s. There was a 0.5-s fixation cross presented between each pair of words. In a JOL list, each word was also presented for 6 s, with a scale slider appearing below the word during the last 3 s. Participants were prompted to make a JOL when the slider appeared. They made their JOLs by dragging and clicking the scale ranging from 0 (*sure I will not remember it*) to 100 (*sure I will remember it*). If they successfully made a JOL within the 3-s time window, the word and slider remained on screen until the end of the trial, ensuring that the total exposure time (i.e., 6 s) of JOL and no-JOL words was equal. If they failed to provide a JOL, a message box appeared to remind them to carefully make predictions during the required time window for the following words.

After a 5-min distraction task (i.e., solving simple mathematical problems), participants completed an old/new recognition test. The 160 studied and 160 new words were presented one at a time in a random order, with a 0.5 fixation cross presented before each word. Participants were asked to judge whether the on-screen word was "old" (i.e., studied; pressing the "F" key) or "new" (i.e., unstudied; pressing the "J" key). The prompt for keycodes was always presented below each word. The recognition test had no time pressure and no feedback.

Postexperiment Questionnaires. Immediately following the JOL reactivity task, participants answered a series of questions regarding self-rated task interestingness, difficulty, focus, effort, and motivation (e.g., "How interesting do you think the memory task was?") on a slider ranging from 1 (*not at all*) to 7 (*very much*). Then, participants completed the Mind-Wandering Questionnaire (Mrazek et al., 2013), with a scale ranging from 1 (*almost never*) to 6 (*almost always*). Higher scores indicate higher frequency of mind-wandering in daily life.

Cognitive Tests. The MMSE (Folstein et al., 1975) was used for cognitive screening, and all participants included in data analyses in this study scored 25 or above (Radomski & Morrison, 2014). The letter comparison task (Wang et al., 2012) was employed to measure participants' processing speed, with higher scores indicating superior processing speed (scores range 0–48). Working memory was measured using the backward digit span task (Wechsler, 1997), with the accurate repetition of longer digit strings indicating better working memory ability (scores range 2–10). Verbal fluency was assessed using the verbal fluency test (Wechsler, 1997), and the more examples participants correctly provided, the higher their verbal fluency.

Results and Discussion

Table 2 lists hit rates, false alarm rates, and discriminability for all experiments. d' is an index reflecting the ability to discriminate the signal (i.e., old words) from the noise (i.e., new words). Below, we focus on the measure of d'. It should be noted that the result patterns for hit rates and d' are similar. Results regarding item-by-item JOLs are reported in the Supplemental Materials. As a summary, those results showed that older adults' average JOLs were generally aligned with their recognition performance, and the relative accuracy of JOLs was significantly greater than chance (i.e., older adults were able to distinguish well-studied words from less-well-studied ones).

Frequentist and Bayesian paired t tests showed that d' for JOL words ($M = 1.49$, $SD = 0.54$) was significantly greater than that for no-JOL words ($M = 1.20$, $SD = 0.35$), difference = 0.30, 95% CI [0.14, 0.46], $t(28) = 3.76$, $p < .001$, $d = 0.70$, Bayes factor $(\text{BF})_{10} = 40.40$ (see Figure 1), indicating a positive reactivity effect on older adults' recognition memory. As illustrated in the violin plot, a majority (75.9%; 22 out of 29) of older participants demonstrated a positive reactivity effect, and a minority (20.7%) showed a negative reactivity effect, with only one showing no reactivity effect. The proportion showing positive reactivity was substantially larger than the proportion showing negative reactivity, $\chi^2(1) = 9.14$, $p = .002$, and also substantially larger than the proportion showing no reactivity, $\chi^2(1) = 19.17$, $p < .001$. Overall, these results revealed that making item-by-item JOLs can reactively enhance older adults' recognition memory for word lists.

Experiment 2

As far as we know, Experiment 1 is the first to demonstrate a positive reactivity effect on older adults' recognition memory. Experiment 2 was conducted to replicate the main findings of Experiment 1. More importantly, Experiment 2 also aimed to explore potential age-related differences in the JOL reactivity effect on recognition memory between older and young adults.

Method

Design and Participants

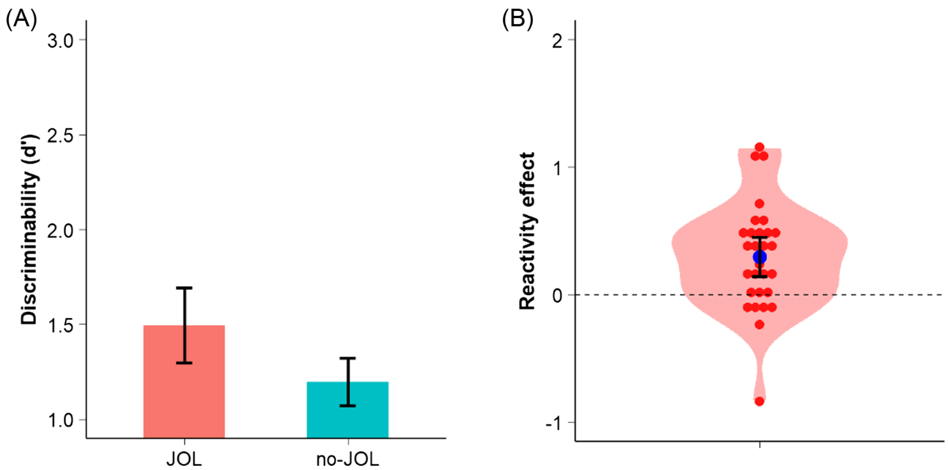
Experiment 2 involved a 2 (Age Group: Young vs. Older Adults) × 2 (Study Method: JOL vs. No-JOL) mixed-factor design, with study

Table 2
Means (Standard Deviations) for Hit Rates, FA Rates, and d′ in Experiments 1–3

Experiment	Hit rate		FA	d'	
	JOL	No-JOL		JOL	No-JOL
Experiment 1	0.72 (0.20)	0.65 (0.18)	0.25 (0.16)	1.49 (0.54)	1.20 (0.35)
Experiment 2					
Older group	0.74 (0.21)	0.70 (0.20)	0.30 (0.17)	1.34 (0.42)	1.18 (0.38)
Young group	0.88 (0.09)	0.75 (0.16)	0.17 (0.15)	2.41 (0.75)	1.92 (0.96)
Experiment 3					
Older group	0.73 (0.17)	0.67 (0.20)	0.26 (0.19)	1.42 (0.47)	1.28 (0.52)
Young group	0.87 (0.11)	0.78 (0.17)	0.17 (0.17)	2.45 (0.84)	2.13 (1.04)

Note. FA = false alarm; JOL = judgment of learning.

Figure 1
Recognition Results of Experiment 1



Note. Panel A: d' for JOL and no-JOL words. Panel B: Violin plot depicting the distribution of the reactivity effect (i.e., the difference in d' between JOL and no-JOL words). Each red dot represents one participant's reactivity effect score, and the blue point represents group average. Error bars represent 95% confidence interval. It should be clarified that only one red dot has a value of 0. JOL = judgment of learning. See the online article for the color version of this figure.

method manipulated within-subjects. According to the effect size observed in Experiment 1 ($d = 0.70$), a power analysis indicated that at least 19 older participants were required to detect a significant reactivity effect at 0.80 power. To be more conservative, we decided to increase the sample size to 30. A total of 32 older adults (age range 64–78, $M_{age} = 67.88$, $SD = 3.11$; 21 female) were recruited from the local community, and no one had previously participated in Experiment 1. In addition, 30 young adults (age range 19–29, $M_{age} = 22.50$, $SD = 2.24$; 21 female) were recruited from the Beijing Normal University participant pool. All participants received 60 renminbi for compensation.

Materials and Procedure

The materials and procedure were identical to those in Experiment 1. Older and younger participants followed the same procedure to complete the JOL reactivity task and subsequent questionnaires and cognitive tests.

Results and Discussion

Frequentist and Bayesian repeated-measures analyses of variances (ANOVAs) were conducted, with age group as a between-subjects variable, study method as a within-subjects variable, and d' as the dependent variable. As shown in Figure 2, there was a main effect of study method, $F(1, 60) = 27.93$, $p < .001$, $\eta_p^2 = .32$, $BF_{incl} = 1.83e+3$, indicating an overall positive reactivity effect on recognition memory. The main effect of age group was also significant, $F(1, 60) = 33.15$, $p < .001$, $\eta_p^2 = .36$, $BF_{incl} = 3.38e+4$, with superior recognition performance in the young compared to the older group. Of critical interest, the interaction between study method and age group was significant, $F(1, 60) = 7.47$, $p = .008$, $\eta_p^2 = .11$, $BF_{incl} = 4.80$, suggesting a moderating role of age in the JOL reactivity effect. As shown in Figure 3A, the interaction derived from the fact that the reactivity effect in older adults was smaller than the effect in young adults.

For older participants, frequentist and Bayesian t tests showed that their recognition performance for JOL words ($M = 1.34$, $SD = 0.42$) was significantly higher than that for no-JOL words ($M = 1.18$, $SD = 0.38$), difference = 0.16, 95% CI [0.03, 0.29], $t(31) = 2.45$, $p = .02$, $d = 0.43$, $BF_{10} = 2.45$. The proportion (68.8%, 22 out of 32) showing positive reactivity was substantially larger than the proportions showing negative reactivity (28.1%), $\chi^2(1) = 5.45$, $p = .02$, and showing no reactivity (3.1%), $\chi^2(1) = 19.17$, $p < .001$.

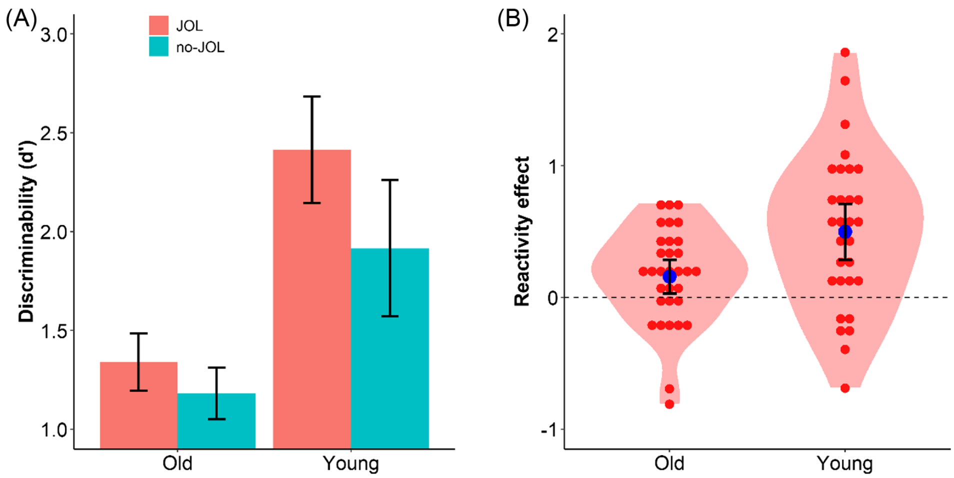
For young participants, their recognition performance for JOL words ($M = 2.41$, $SD = 0.75$) was also significantly greater than that for no-JOL words ($M = 1.92$, $SD = 0.96$), difference = 0.50, 95% CI [0.28, 0.72], $t(29) = 4.60$, $p < .001$, $d = 0.84$, $BF_{10} = 331$. The proportion (80.0%; 24 out of 30) of young participants showing positive reactivity was larger than the proportion (20.0%) showing negative reactivity, $\chi^2(1) = 10.80$, $p = .001$.

Overall, these results successfully replicated the positive reactivity effect on recognition memory for both young and older participants. In addition, Experiment 2 provided the first demonstration that the reactivity effect on recognition memory was weaker for older than for young adults.

Experiment 3

Although Experiments 1 and 2 have consistently observed a positive reactivity effect on older adults' recognition memory, which components (i.e., recollection or familiarity) of older adults' recognition memory making JOLs improve remains unknown. Zheng et al. (2024) found that making JOLs can enhance young adults' recognition memory by equally improving recollection and familiarity components of recognition memory. Further exploration is needed to determine the roles of recollection and familiarity in the

Figure 2
Recognition Results of Experiment 2



Note. Panel A: d' as a function of study method and age group. Panel B: Violin plot depicting the distribution of the reactivity effect of JOLs (i.e., the difference in d' between JOL and no-JOL words) in the older and young groups. Each red dot represents one participant's reactivity effect score, and the blue points represent group averages. Error bars represent 95% confidence interval. JOL = judgment of learning. See the online article for the color version of this figure.

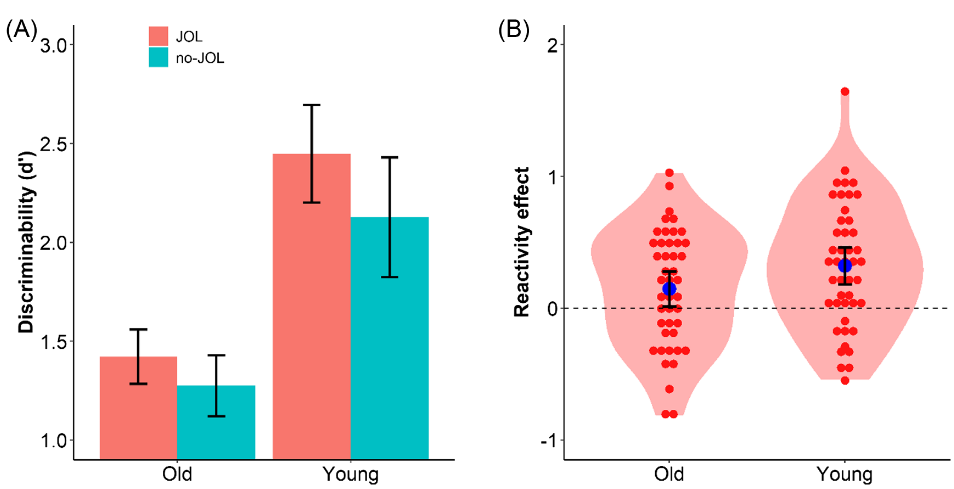
reactivity effect for older adults. Experiment 3 was designed to explore this important question by utilizing the R/K procedure.

Method

Design and Participants

Experiment 3 involved a 2 (Age Group: Young vs. Older Adults) × 2 (Study Method: JOL vs. No-JOL) mixed design, with study method manipulated within-subjects. According to the effect size observed in Experiment 2 (d = 0.43), the power analysis indicated that 45 older participants were required to detect a significant reactivity effect at 0.80 power. A total of 48 older adults were recruited from the local community, four of whom were excluded from the analysis. Two participants did not achieve a minimum score of 25 on the MMSE, and the other two failed to complete the experiment due to computer failure. The final sample consisted of 44 older participants (age range 65–76, M_{age} = 68.82, SD = 2.87; 27 female). Besides, 45 young

Figure 3
Results of d′ in Experiment 3



Note. Recognition results of Experiment 3. Panel A: d' as a function of study method and age group. Panel B: Violin plot depicting the distribution of the reactivity effect of JOLs (i.e., the difference in d' between JOL and no-JOL words) in the older and young groups. Each red dot represents one participant's reactivity effect score, and the blue points represent group averages. Error bars represent 95% confidence interval. JOL = judgment of learning. See the online article for the color version of this figure.

participants (age range 18–26, M_{age} = 21.78, *SD* = 1.95; 31 female) were recruited. All participants had not participated in previous experiments and received compensation.

Materials and Procedure

The materials and procedure were identical to those in Experiment 2, except for one difference in the recognition test. During the recognition test, the familiarity- and recollection-based processes of recognition memory were assessed using the R/K procedure (Yonelinas, 2002), in which participants were asked first to provide an old/new response followed by an R/K response. Specifically, the 160 studied and 160 new words were presented one-by-one in a random order. Participants were instructed to judge whether the on-screen word was "new" (pressing the "Z" key) or "old" (pressing the "X" key). If a "new" response was made, the next test trial started automatically. If an "old" response was made, participants had to further identify whether the response was made based on "familiar" (pressing the "<" key) or "remember" (pressing the ">" key). The term "familiar" was used instead of the standard term "know" for the aim to avoid confusion due to the vague meaning of the word "know" outside of memory researchers. There was a 500-ms blank interval between "old/new" and "R/K" judgments and a 500-ms fixation cross between each test trial.

The procedure and instructions for the R/K task were taken from Zheng et al. (2024), which were adapted from Ozubko et al. (2012). Participants were instructed to make "remember" responses when they were able to consciously recall specific details or thoughts associated with the word and make "familiar" responses if they felt a sense of familiarity but without any specific conscious recollection. After explaining the instructions, participants were asked if they had any questions about the test requirements. If necessary, the experimenter reexplained the distinction between "remember" and "familiar" responses until participants no longer demonstrated confusion. At the end of the experiment, participants were briefly interviewed and asked to provide examples of each type of responses. The results indicated that all participants understood and complied with the task requirements.

Results and Discussion

Regarding d', frequentist and Bayesian 2 (Age Group: Young vs. Older Adults) × 2 (Study Method: JOL vs. No-JOL) repeated-measures ANOVAs were conducted. As shown in Figure 3, the analyses revealed a main effect of study method, $F(1, 87) = 22.71$, $p < .001$, $\eta_p^2 = .21$, $BF_{incl} = 1.58e+3$, indicating a generally positive reactivity effect on recognition memory. The main effect of age group was also significant, $F(1, 87) = 37.94$, $p < .001$, $\eta_p^2 = .30$, $BF_{incl} = 3.15e+5$, with young participants exhibiting superior recognition performance compared to older participants. Moreover, the interaction between study method and age group was marginally significant, $F(1, 87) = 3.17$, $p = .079$, $\eta_p^2 = .04$, $BF_{incl} = 1.50$, suggesting certain differences in the magnitude of reactivity effects between the older and young groups.

For older participants, their recognition performance for JOL words ($M = 1.42$, $SD = 0.47$) was significantly higher than that for no-JOL words ($M = 1.28$, $SD = 0.52$), difference = 0.15, 95% CI [0.01, 0.28], $t(43) = 2.17$, $p = .035$, $d = 0.33$, $BF_{10} = 1.36$. The proportion (61.4%, 27 out of 44) showing positive reactivity was marginally larger than the proportion (36.4%) showing negative reactivity, $\chi^2(1) = 2.81$, $p = .09$, and substantially larger than the proportion (2.3%) showing no reactivity, $\chi^2(1) = 24.14$, $p < .001$.

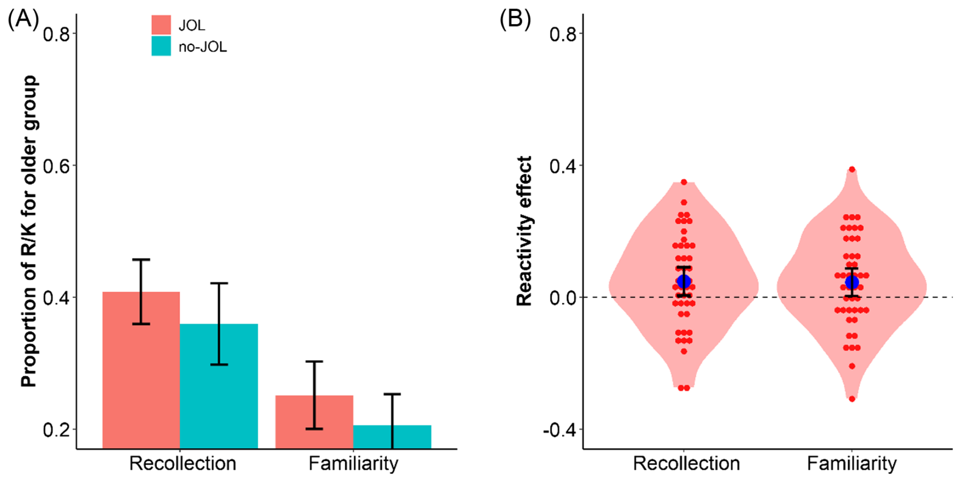
For young participants, their recognition performance for JOL words ($M = 2.45$, $SD = 0.84$) was significantly greater than that for no-JOL words ($M = 2.13$, $SD = 1.04$), difference = 0.32, 95% CI [0.18, 0.47], $t(44) = 4.51$, $p < .001$, $d = 0.67$, $BF_{10} = 468$. The proportion (68.9%; 31 out of 45) of young participants showing positive reactivity was substantially larger than the proportion (22.2%) showing negative reactivity, $\chi^2(1) = 10.76$, $p = .001$, and also substantially larger than the proportion (8.9%) showing no reactivity, $\chi^2(1) = 20.83$, $p < .001$.

When considering R/K responses, the independence R/K method (Yonelinas & Jacoby, 1995) was adopted to calculate recollection and familiarity estimates. Recollection was calculated by subtracting the proportion of "remember" responses to new items from the proportion of "remember" responses to old items (i.e., $R = R_{old} - R_{new}$). Familiarity was calculated by subtracting the familiarity estimate for new items from the familiarity estimate for old items (i.e., $F = F_{old} - F_{new}$). Specifically, familiarity for old items was measured by dividing the proportion of "know" responses to old items by one minus the proportion of "remember" responses to those items (i.e., $F_{old} = K_{old}/[1 - R_{old}]$). Familiarity for new items was measured by dividing the proportion of "know" responses to new items by one minus the proportion of "remember" responses to those items (i.e., $F_{new} = K_{new}/[1 - R_{new}]$). These formulas incorporate the assumption that the familiarity and recollection processes vary independently, and also correct for false alarms (Cohen et al., 2017; Parks et al., 2010; Yonelinas & Jacoby, 1995). Since there was no three-way interaction ($p = .55$; $BF_{incl} = 0.25$), we conducted separate 2 (Study Method: JOL vs. No-JOL) × 2 (Recognition Type: Recollection vs. Familiarity) repeated-measures ANOVAs for older and young groups.

For older participants (see Figure 4), there was a main effect of study method, $F(1, 43) = 6.39$, $p = .015$, $\eta_p^2 = .13$, $BF_{incl} = 3.49$, with superior recollection and familiarity proportions for JOL words than for no-JOL words. A main effect of recognition type was also observed, $F(1, 43) = 21.77$, $p < .001$, $\eta_p^2 = .34$, $BF_{incl} = 565.68$, with higher recollection proportion than familiarity proportion. More importantly, there was no significant interaction between study method and recognition type, $F(1, 43) = 0.02$, $p = .90$, $\eta_p^2 = 3.51e{-}4$, $BF_{incl} = 0.22$, indicating no detectable difference between the reactivity effects on recollection and familiarity.

Specifically, older participants' recollection for JOL words ($M = 0.41$, $SD = 0.17$) was significantly higher than that for no-JOL words ($M = 0.36$, $SD = 0.21$), difference = 0.05, 95% CI [0.01, 0.09], $t(43) = 2.23$, $p = .031$, $d = 0.34$, $BF_{10} = 1.52$. The proportion (63.6%, 28 out of 44) showing positive reactivity was larger than the proportion (34.1%) showing negative reactivity, $\chi^2(1) = 3.93$, $p = .047$, and also substantially larger than the proportion (2.3%) showing no reactivity, $\chi^2(1) = 25.14$, $p < .001$. Regarding familiarity estimates, older participants' familiarity proportion for JOL words ($M = 0.25$, $SD = 0.17$) was significantly higher than that for no-JOL words ($M = 0.21$, $SD = 0.16$), difference = 0.05, 95% CI [0.003, 0.09], $t(43) = 2.14$, $p = .038$, $d = 0.32$, $BF_{10} = 1.29$. The proportion (59.1%, 26 out of 44) showing positive reactivity was numerically larger than the proportion (38.6%) showing negative reactivity, $\chi^2(1) = 1.88$, $p = .17$, and also substantially larger than

Figure 4
Results of Recollection and Familiarity for Older Adults in Experiment 3



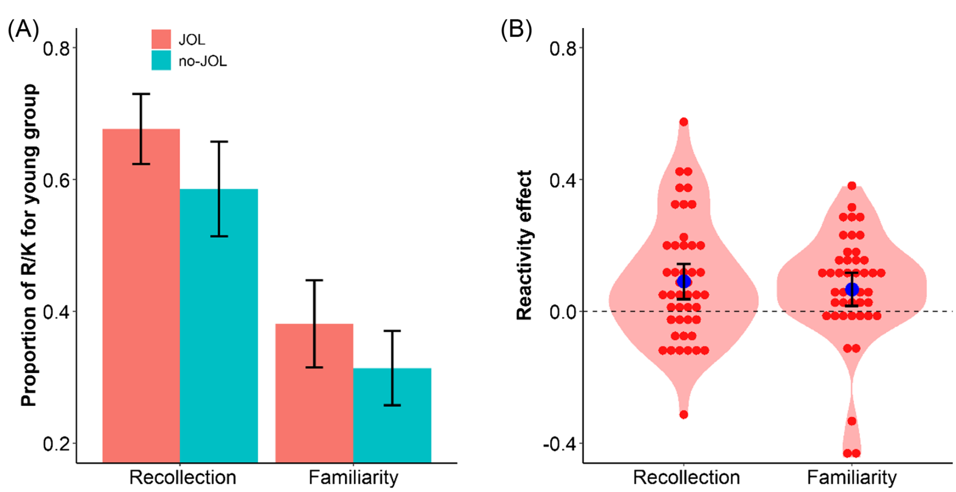
Note. Panel A: The proportions of recollection and familiarity for JOL and no-JOL conditions in the older group. Panel B: Violin plot depicting the distribution of the reactivity effect (i.e., the difference in R/K response between JOL and no-JOL words). Each red dot represents one participant's reactivity effect score, and the blue points represent group averages. Error bars represent 95% confidence interval. JOL = judgment of learning; R/K = remember/know. See the online article for the color version of this figure.

the proportion (2.3%) showing no reactivity, $\chi^2(1) = 23.15$, $p < .001$.

For young participants (see Figure 5), there was a main effect of study method, $F(1, 43) = 13.45$, $p < .001$, $\eta_p^2 = .24$, $BF_{incl} = 39.95$, with higher recollection and familiarity proportions for JOL words compared to no-JOL words. A main effect of recognition type was also observed, $F(1, 43) = 59.06$, $p < .001$, $\eta_p^2 = .58$, $BF_{incl} = 7.06e+6$, with higher recollection proportion than familiarity proportion. Moreover, their interaction was not significant, $F(1, 43) = 0.67$, $p = .42$, $\eta_p^2 = .02$, $BF_{incl} = 0.31$, suggesting minimal difference in the reactivity effect on recollection and familiarity.

Specifically, young participants' recollection for JOL words ($M = 0.68$, $SD = 0.18$) was significantly higher than that of no-JOL words ($M = 0.59$, $SD = 0.25$), difference = 0.09, 95% CI [0.04, 0.15],

Figure 5
Results of Recollection and Familiarity for Young Adults in Experiment 3



Note. Panel A: The proportions of recollection and familiarity for JOL and no-JOL conditions in the young group. Panel B: Violin plot depicting the distribution of the reactivity effect (i.e., the difference in R/K response between JOL and no-JOL words). Each red dot represents one participant's reactivity effect score, and the blue points represent group averages. Error bars represent 95% confidence interval. JOL = judgment of learning; R/K = remember/know. See the online article for the color version of this figure.

$t(44) = 3.36$, $p = .002$, $d = 0.50$, $BF_{10} = 19.03$. The proportion (64.4%, 29 out of 45) showing positive reactivity was substantially larger than the proportion (31.1%) showing negative reactivity, $\chi^2(1) = 5.23$, $p = .022$, and was also substantially larger than the proportion (4.4%) showing no reactivity, $\chi^2(1) = 23.52$, $p < .001$. Regarding familiarity estimates, young participants' familiarity proportion for JOL words ($M = 0.38$, $SD = 0.22$) was significantly higher than that for no-JOL words ($M = 0.31$, $SD = 0.19$), difference = 0.07, 95% CI [0.02, 0.12], $t(43) = 2.62$, $p = .012$, $d = 0.40$, $BF_{10} = 3.34$. The proportion (75.0%, 33 out of 44)[1] showing positive reactivity was substantially larger than the proportion (25.0%) showing negative reactivity, $\chi^2(1) = 11.00$, $p < .001$.

Overall, Experiment 3 successfully replicated the positive reactivity effect on recognition memory in both young and older adults and age-related decrease in reactivity effect. The findings further revealed that making JOLs reactively facilitates recognition memory by boosting recollection- and familiarity-based recognition, which was true for both age groups.

Transparency and Openness

We report how we determined sample sizes, all data exclusions, all manipulations, and all measures in this study. The deidentified data on which the study conclusions are based, the analytical code necessary to reproduce analyses, and the materials used in this study are publicly available on the Open Science Framework at https://osf.io/v7fye/ (Zheng, 2024, July 13). Data were analyzed using JASP 0.17.3 (an open-source statistical software; https://jasp-stats.org) and Mplus 8.3 (Muthén & Muthén, 2017). This study was not preregistered.

Structural Equation Modeling

To directly test the ELE theory and the dual-task hypothesis, we merged data from the three experiments ($N = 180$) and explored the potential mediating roles of learning engagement and cognitive ability in the age-related reactivity effect. This was done by building a SEM with Mplus 8.3 software (Muthén & Muthén, 2017). As shown in Figure 6, the model took age group (*young* = 0; *old* = 1) as the predictor, with participants' learning engagement and cognitive ability as mediators and their average recognition performance (d') and reactivity effect score ($d'_{\text{JOL}} - d'_{\text{no-JOL}}$) as outcomes. The latent variable of learning engagement was constructed by self-rated task interestingness, focus, effort, motivation, and mind-wandering.[2] The latent variable of cognitive ability was constructed by MMSE score, processing speed, working memory, and verbal fluency. The bias-corrected bootstrap method with 5,000 resamples was employed to determine 95% CI (Hayes & Scharkow, 2013). Supplemental Table S1 presents the correlation results of these main measures.

The structural model showed a good fit to the data, $\chi^2/df = 1.85$, comparative fit index = .92, Tucker–Lewis index = .90, root-mean-square error of approximation = .07, standardized root-mean-square residual = .08. The results indicated that age group significantly predicted learning engagement, $\beta = .62$, 95% CI [0.48, 0.73], $p < .001$, with older participants showing more engagement on task compared to young participants. Learning engagement significantly positively predicted recognition performance, $\beta = .24$, 95% CI [0.06, 0.41], $p = .007$, and significantly negatively predicted the magnitude of the reactivity effect, $\beta = -.25$, 95% CI [−0.47, −0.004], $p = .037$. Concretely speaking, the more the participants engaged in the learning task, the better their overall recognition performance became. More importantly, the more the participants engaged in the learning task, the weaker the reactivity effect became (i.e., the less effectively making JOLs enhanced their recognition memory). This finding is consistent with the ELE theory. The weaker positive reactivity effect on older adults' recognition memory at least partially derives from the fact that they engaged more in the learning task than young adults, leaving little room for making JOLs to further enhance their learning engagement and thus resulting in a weaker positive reactivity effect on their recognition memory.

Additionally, age group was a significant predictor of cognitive ability, $\beta = -.91$, 95% CI [−0.95, −0.86], $p < .001$, with older participants exhibiting inferior cognitive ability compared to young participants. Cognitive ability positively predicted recognition performance, $\beta = .53$, 95% CI [0.11, 1.09], $p = .034$, but did not predict the magnitude of the reactivity effect, $\beta = .06$, 95% CI [−0.51, 0.61], $p = .84$. These results reflected that, for participants with superior cognitive ability, their overall recognition performance was higher. Critically, cognitive ability could not predict the magnitude of the reactivity effect, challenging the dual-cost hypothesis. Put differently, these results suggested that the weaker positive reactivity effect on older adults' recognition memory cannot be attributed to their declined cognitive ability.

Table 3 reports the mediation results. The indirect effect of age group on recognition performance through learning engagement was significant (indirect effect = .15, 95% CI [0.04, 0.28], $p = .016$), and the indirect effect through cognitive ability was significant as well (indirect effect = −.48, 95% CI [−1.02, −0.11], $p = .04$). The results indicated that age improved older participants' recognition performance by increasing their learning engagement, while it also impaired their recognition performance by decreasing their cognitive ability. After controlling for the mediators, the direct effect of age group on recognition performance was no longer significant (direct effect = −.34, 95% CI [−0.74, 0.22], $p = .16$). These findings suggested that age-related differences in recognition memory were fully mediated by age-related differences in learning engagement and cognitive ability.

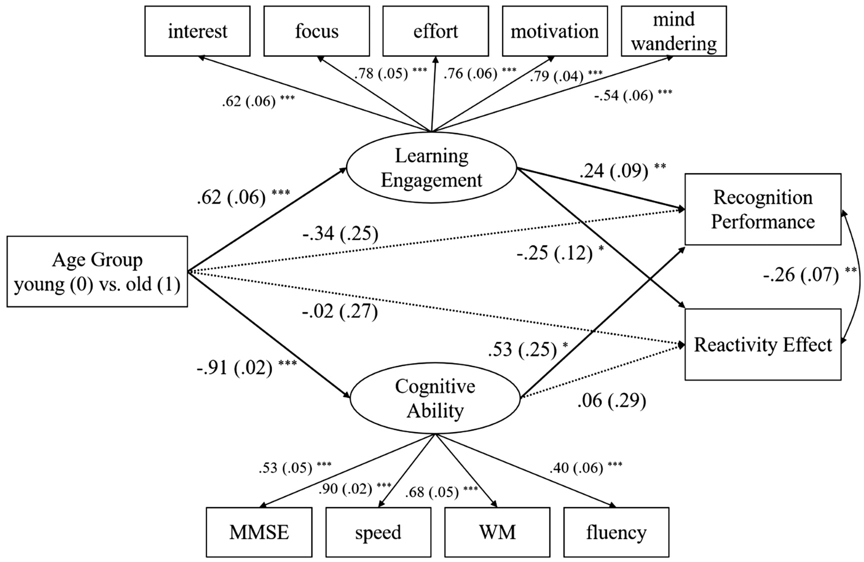
Of critical importance, the indirect effect of age group on the reactivity effect through learning engagement was significant (indirect effect = −.15, 95% CI [−0.31, −0.01], $p = .048$), while the indirect effect through cognitive ability was nonsignificant (indirect effect = −.05, 95% CI [−0.56, 0.47], $p = .84$). Thus, age diminished older participants' reactivity effect by increasing their learning engagement, but the indirect effect of cognitive ability was minimal. The direct effect of age group on the reactivity effect was no longer significant (direct effect = −.02, 95% CI [−0.55, 0.54], $p = .96$), suggesting that learning engagement played a full mediating role in age-related differences in the reactivity effect. Taken together, these findings supported the ELE theory as an account for the age-related

[1] One young participant was unable to calculate the corrected familiarity estimate due to lack of false alarm.

[2] Self-rated task difficulty was excluded from the measurement model of learning engagement because its factor loading was small and nonsignificant ($\beta = .09$, $p = .30$).

Figure 6

Model Testing Mediation Effects of Learning Engagement and Cognitive Ability



Note. Numbers outside of the brackets are the standardized coefficients, and numbers inside the brackets are the standard errors. The solid lines represent significant paths, and the dashed lines represent insignificant paths. Gender, education, and self-rated health (i.e., physical and mental) were controlled for but were not shown for simplicity of presentation. MMSE = Mini-Mental State Examination; WM = working memory; vs. = versus.
$^{*}p < .05$. $^{**}p < .01$. $^{***}p < .001$.

reactivity effect on recognition performance and ran in contrast to the dual-task hypothesis.

General Discussion

The ability to recognize stimuli encountered previously is crucial for individuals across various age populations (Fraundorf et al., 2019). Previous studies have shown that the act of making JOLs can enhance young adults' recognition memory (Li et al., 2022, 2023; Tekin & Roediger, 2020) through facilitating both recollection and familiarity components (Zheng et al., 2024). The present study is the first to explore whether making JOLs can improve older adults' recognition memory and investigates age-related differences in JOL reactivity. Three experiments consistently showed that making JOLs significantly improved older participants' recognition memory for word lists, although the positive reactivity effect for older participants was relatively smaller than that for young participants. The SEM results further demonstrated that older adults' greater learning engagement, rather than their declined cognitive ability, contributed to age-related decreases in the reactivity effect. Experiment 3 also indicated that, similar to young participants, making JOLs can enhance older participants' recognition memory by boosting both recollection and familiarity.

This study is the first to document a positive reactive influence of making JOLs on older adults' recognition memory of word lists. According to the ELE theory (Shi et al., 2023), the requirement of making JOLs compels learners to carefully encode and analyze study items, which in turn enhances learning engagement (e.g., attention) and results in a positive reactivity effect. Prior research has indicated that the act of making JOLs can help maintain attention to the learning task at hand (Carpenter & Schacter, 2018; Shi et al., 2023), while distracting attention during the encoding phase causes substantial damage to recognition memory for both young and older adults (Ballesteros & Mayas, 2015; Fernandes et al., 2006). Shi et al. (2023) have demonstrated the role of enhanced learning engagement in the positive JOL reactivity on young adults' recognition memory.

Table 3

Bootstrap Estimates of Indirect Effects of Learning Engagement and Cognitive Ability

	Recognition performance			Reactivity effect		
Effect	Estimate	*SE*	95% CI	Estimate	*SE*	95% CI
Direct effect	−.34	.25	[−0.74, 0.22]	−.02	.27	[−0.55, 0.54]
Indirect effect of LE	.15	.06	[0.04, 0.28]	−.15	.08	[−0.31, −0.01]
Indirect effect of CA	−.48	.23	[−1.02, −0.11]	−.05	.26	[−0.56, 0.47]

Note. *SE* = standard error; CI = confidence interval; LE = learning engagement; CA = cognitive ability.

Therefore, we infer that making JOLs can also enhance older adults' learning engagement, thus enhancing their recognition memory.

When considering the specific process by which making JOLs enhances recognition memory, the results revealed that making JOLs can simultaneously promote recollection- and familiarity-based recognition. On the one hand, making JOLs forces learners to focus more on mnemonic characteristics of each item (Koriat, 1997), which in turn increases the likelihood of recalling specific details of JOL words. On the other hand, the sustained attention during learning can enhance the overall memory strength of JOL words (Criss, 2009; MacDonald & MacLeod, 1998), thereby aiding learners in successfully identifying them based on familiarity. That is, enhanced learning engagement may produce a certain encoding advantage to improve item recollection (see below for detailed discussion), and it can also improve item familiarity in a direct way. This works for both young and older adults.

The positive reactivity effects on recollection and familiarity may explain why making JOLs can enhance older adults' recognition memory instead of their cued recall performance (Tauber & Witherby, 2019). Cued recall tests primarily rely on conscious recollection of cue–target relational information (Peterson & Mulligan, 2013), whereas both recollection- and familiarity-based recognition contribute to recognition performance (Yonelinas, 2002). The additional boost to item familiarity induced by making JOLs can assist older adults in completing recognition tests, while its benefits for cued recall tests are minimal. Moreover, remembering any contextual details aside from semantic associations with target items can aid older adults in discriminating them from new items. As suggested by the distinctiveness theory proposed by Zheng et al. (2024), the process of making JOLs can enrich encoding characteristics (i.e., contextual details) of study items, thus enhancing recollection-based recognition. Specifically, besides activating semantic information related to the item being judged, making JOLs may also induce some other contextual details, such as information about whether one has made a JOL for a particular item, and the JOL values assigned to different items. All these pieces of information increase the distinctiveness of JOL items relative to no-JOL items and new items, so that any retrieval of distinctive information should facilitate recollection-based recognition. Thus, when learning a list of unrelated words, older adults' item recollection can benefit from increased distinctiveness (e.g., Geraci et al., 2009; Leshikar et al., 2015; Lin & MacLeod, 2012; Troyer et al., 2006).

Despite the fact that the specific processes of making JOLs to enhance recognition memory are similar for older and young adults, the overall reactivity effect on recognition memory for older adults is significantly weaker than that for young adults. The SEM results indicate that the ELE theory is valid to account for these age-related differences in the positive reactivity effect on recognition memory, but the dual-task hypothesis is less valid. As speculated by Tauber and Witherby (2019), older participants have a greater enthusiasm for participating in experimental tasks. Consistent with this claim, the present study found that older participants perceived the memory task as more interesting, focused more on the memory task, and exerted greater effort and were more motivated to complete this task. Also, consistent with previous research (Jordão et al., 2019; Maillet et al., 2018), the present study found that older participants reported fewer instances of mind-wandering in daily life. More crucially, learning engagement, as constructed by these indicators, fully mediated age-related differences in the magnitude of the reactivity effect. That is to say, the inherently higher learning engagement of older adults diminishes the potential of making JOLs in enhancing learning engagement, consequently leading to a weaker enhancement effect on their recognition performance.

The SEM results also show that the indirect effect of cognitive ability on age differences in the reactivity effect was not detectable, which is inconsistent with the dual-task hypothesis. According to this hypothesis, due to declined cognitive ability, it is more challenging for older participants to simultaneously perform the memory task and the JOL task, resulting in greater dual-task costs and a weaker positive reactivity effect for older adults. In contrast to this hypothesis, the results documented here indicate that, although overall cognitive ability (constructed by processing speed, verbal fluency, working memory, and other indicators) in older participants was lower than in young participants (Baltes & Lindenberger, 1997; Nettelbeck & Burns, 2010), the difference in cognitive ability could not explain the difference in the reactivity effect between the older and young groups of participants. On one hand, unlike concurrent tasks (e.g., continuous visual or auditory choice reaction time task) that are irrelevant to learning tasks (Curran, 2004; Naveh-Benjamin & Brubaker, 2019), JOL tasks are closely related to the materials being studied, which should not interfere with concurrent learning. On the other hand, older participants exhibited a high completion rate in JOL tasks, and their judgments were relatively accurate (see JOL results in the Supplemental Material), suggesting that older participants are capable of handling the dual tasks in this study. Thus, engaging in JOLs while learning word lists did not impose a significant cognitive load on older adults. Of course, when the learning task is excessively difficult (e.g., learning unrelated word pairs within a limited timeframe), dual-task costs are likely to arise (Murphy et al., 2024).

Besides the theoretical implications discussed above, this study also carries some practical implications by incorporating the results of prior research. Given the global challenges posed by an aging society, finding a simple and effective intervention to enhance memory performance for older adults should be very meaningful. Many previous studies have demonstrated the effectiveness of metacognitive interventions based on training self-regulation skills in promoting older adults' memory performance (for a review, see Sella et al., 2023). For instance, Dunlosky et al. (2003) trained older participants to use self-testing to discover which items they had not learned well and then instructed them to allocate subsequent study time to those items. These studies emphasize the critical role of accurate metacognitive monitoring. Nonetheless, the evidence regarding the preservation of older adults' metacognitive monitoring ability is mixed (Castel et al., 2016; Palmer et al., 2014). Insights from the JOL reactivity literature enlighten us that utilizing the direct effects of metacognitive monitoring (i.e., the JOL reactivity effect) holds promise for improving older adults' memory performance, irrespective of their metacognitive ability. As found in this study, soliciting JOLs can reliably enhance older adults' recognition memory for word lists. Engaging in JOLs can effectively maintain attention on ongoing learning (Shi et al., 2023) and deepen encoding (distinctiveness) and overall familiarity of study items (Zheng et al., 2024). Therefore, guiding learners to making JOLs can be a simple and practical strategy that demands minimal time or reliance on trainers. Thus, it is very feasible to implement training programs based on making JOLs in home or community settings to improve older adults' recognition memory, which is essential for their daily functioning. In addition, given the potential dual-task costs (Mitchum et al., 2016; Murphy et al., 2024), it is necessary to reduce cognitive costs associated with making JOLs, such as by allowing sufficient time for learning.

It should be acknowledged that this study has some limitations. Recent studies have shown that making JOLs can improve long-term memory for a period of 1–2 days (Witherby & Tauber, 2017; Zheng et al., 2024). As the retention interval increases, recollection responses decline rapidly, while familiarity responses decline relatively slowly (Gardiner & Java, 1991; Hockley & Consoli, 1999; Meier et al., 2013). Thus, it remains uncertain whether the positive reactivity effect on older adults' recognition memory persists over time and whether the specific contributions of recollection and familiarity to this effect vary as a function of retention interval. Furthermore, beyond verbal materials, older adults often encounter memory tasks that involve more life-related stimuli, such as recognizing whether a face is a known associate or a stranger. It is also unclear whether the reactivity effect extends to recognition memory of other types of stimuli (e.g., faces, objects). Finally, future research is encouraged to explore the reactive influence of making JOLs on older adults' memory in real-world settings (such as shopping scenarios) and on other memory domains (such as prospective memory; Meier et al., 2011; Rummel et al., 2013).

Finally, although this study focuses on recognition memory, it is worth discussing why older adults' associative memory cannot benefit from JOL reactivity. We infer that when learning related word pairs, older adults' associative processing deficits (Craik & Rose, 2012; Naveh-Benjamin et al., 2007) may hinder their ability to benefit from the cue–target associations strengthened by making JOLs (Soderstrom et al., 2015). This reflects a failure among older adults to strengthen cue–target relatedness, which may stem from their decreased ability to bind information together or from forming excessive associations (for a review, see Campbell & Davis, 2024). The former suggests that while older adults focus their attention on associative information by making JOLs, their weakened ability to consolidate these bindings (i.e., binding deficit; Chalfonte & Johnson, 1996) hinders their response to these benefits. The latter indicates that older adults are prone to forming more nontarget associations (i.e., hyperbinding; Campbell et al., 2010), where both target and nontarget associations may be strengthened by making JOLs. Future explorations on these issues are called for.

Conclusions

The act of making JOLs can improve older adults' recognition memory through enhancing both recollection and familiarity. The positive reactivity effect of making JOLs on recognition memory is relatively smaller for older than for young adults. The ELE theory can readily account for the positive reactivity effect and age-related differences in this effect.

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