Psychonomic Bulletin & Review (2026) 33:204
https://doi.org/10.3758/s13423-026-02971-y

REGISTERED REPORTS & REPLICATIONS

Context reinstatement reveals preserved context memory specificity in typical ageing

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Received: 5 December 2025 / Accepted: 4 July 2026

Abstract
Episodic memory specificity declines with healthy ageing, as reflected in older adults' impaired ability to discriminate between similar focal stimuli. Yet, little is known about how ageing alters specificity of contextual memory features. Context reinstatement studies showed that young adults incidentally encode task-irrelevant contextual features with a high degree of specificity: focal objects are more frequently judged old when shown with studied backgrounds than with slightly altered lure backgrounds. In this registered report, we investigated the effect of context reinstatement with same, different, and visually similar lure background scenes on mnemonic discrimination for objects in younger and older adults. We found a gradual increase in old responses to both target and lure objects between different, lure, and same context conditions. Contrary to our hypothesis, this effect was present in both age groups, although older adults had a general bias towards old responses. These findings suggest that like younger adults, older adults integrate highly detailed contextual features into episodic memory traces, and that these features can influence mnemonic discrimination responses. Overall, this study highlights the value of indirect tests of context memory to study episodic memory in typical ageing.

Keywords Cognitive ageing · Context reinstatement · Recognition memory

Introduction

Episodic memory, the ability to retrieve personally experienced events contextualised in space and time, is well known to decline with typical ageing. Older adults (OAs) show a reduction of memory specificity, and tend to rely on more general memory representations, or *gists* (Greene & Naveh-Benjamin, 2023; Grilli & Sheldon, 2022). For instance, they produce less details than younger adults (YAs) when recalling personal past events in autobiographical memory tasks (Levine et al., 2002; Piolino et al., 2002). However, the mechanisms underlying age-related changes in memory representations are not yet fully understood.

Maintaining specific memory traces over time requires efficient pattern-separation, the computational mechanism by which similar episodes are encoded as non-overlapping (or orthogonalized) memory traces (O'Reilly & McClelland, 1994). In most studies, the behavioural manifestation of pattern separation is assessed by measuring participants' ability to discriminate target object images from visually similar lure object images in a recognition memory task, typically with the mnemonic similarity task (MST) (Stark et al., 2019). The target image and its lure pair can differ in

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Published online: 03 August 2026

a wide range of characteristics, including the orientation, the size, or the colour of the object. Lure discrimination is impaired in normal ageing (Stark & Stark, 2017; Stark et al., 2013), which is interpreted as an age-related decline in pattern separation. The MST, however, exclusively assesses the specificity of memory for the central (focal) elements of the memory task (i.e., the objects), leaving out an essential dimension of episodic memory: the context. Context refers to features aside from the focal, target information that is irrelevant or incidental to the task (Hayes et al., 2007). How ageing alters the specificity of contextual features of memory representations, and whether it does so to the same extent as for the focal information, thus remains unclear. This question is of considerable importance since we routinely make memory-guided decisions, whether implicitly or explicitly (Pillemer, 2003). Therefore, reduced specificity of contextual features may be one of the mechanisms by which the age-related memory changes affect daily-life behaviours.

Context memory is generally believed to decline in normal ageing, as shown by compelling evidence from source-memory studies (for reviews, see Mitchell & Johnson, 2009; Spencer & Raz, 1995). However, episodic memories are complex, multi-facetted representations that include features of different natures such as visual-spatial context, temporal context, and event narrative. These dimensions may be unequally impacted by ageing, as recent research found that memory for narrative details and temporal organisation of events is preserved in OAs (Delarazan et al., 2023; Fenerci et al., 2024). In contrast, the specificity of memory for visual objects (Jensen et al., 2023; Stark & Stark, 2017; Stark et al., 2013), visual-spatial scenes (Berron et al., 2018; Gellersen et al., 2023; Snytte et al., 2022), and position of objects in scenes (Korkki et al., 2020, 2023) is impaired in ageing. These results suggest that, among the dimensions that constitute the context of an episodic memory representation, visual-spatial context may be the one most affected by the age-related specificity impairment. Yet, in most of the designs used to measure context memory, participants are explicitly instructed to form associations between items and contextual features. In other words, context memory is tested *directly*, allowing participants to use strategies such as unitization, which are known to effectively improve OA's memory performance (Ahmad et al., 2015; Bastin et al., 2013; Naveh-Benjamin et al., 2007). Investigating how ageing alters the contextual information that is *incidentally* integrated into the representations of complex episodes requires testing context memory *indirectly*.

Context reinstatement (CR) provides an appropriate experimental framework for measuring context-dependent memory indirectly. CR effect typically refers to better memory performance when the encoding environment is reinstated at test compared to when the environment is altered between encoding and test (Smith & Vela, 2001). Aside from traditional room changes, recent studies on CR manipulated task-irrelevant information surrounding the focal information, such as scene images used as background for objects in a visual recognition memory task. In such designs, CR is measured by comparing recognition decisions for items placed against the same context image at encoding and test to items for which the context image is different between encoding and test. Using this paradigm in young participants, Doss et al. (2018) reported that CR increases the likelihood of endorsing both target and similar lure objects from the MST as old. Thus, CR modulates both hits and false alarm (FA) rates in recognition memory. In this study, however, participants were asked to decide whether the object belonged to the background scene at encoding, therefore promoting explicit associations between focal and contextual information. Racsmány et al. (2021) replicated these findings in an incidental encoding task followed by a surprise memory test (see also Hayes et al., 2007). Since participants were instructed to make decisions with respect to the objects only during both the incidental encoding task and the recognition memory task, this paradigm allows us to test context memory indirectly. The results showed that task-irrelevant context scenes were *incidentally* integrated into the memory traces as they later influenced recognition. To evaluate the richness of this contextual information in YAs, Szőllősi et al. (2023) used visually similar scenes (i.e., "lure" contexts) instead of different contexts as backgrounds for objects in the recognition memory task. Hits and FA rates for objects increased for same contexts compared with lure contexts even though there were only small visual differences between the same and lure contexts. This finding indicates that YAs incidentally integrate task-irrelevant contextual features into a memory trace with a high degree of detail, enabling mnemonic discrimination of contextual features. This result was replicated in a recent functional neuroimaging study, which further showed that activity in the parahippocampal place area (PPA) distinguishes between same and lure context backgrounds during recognition (Bencze et al., 2024).

Although OAs generally have impaired context memory in direct associative memory tasks, there is evidence that CR effects are preserved in normal ageing when comparing same to different context conditions (Craik & Schloerscheidt, 2011; Naveh-Benjamin & Craik, 1995; Park et al., 1987; Ward et al., 2017). One explanation for this discrepancy is that memory representations become more cluttered with ageing, including more irrelevant and no-longer-relevant information in addition to relevant information (Amer et al., 2022). This framework explains why OAs are impacted by contextual information when it is irrelevant to the task at hand, a phenomenon referred to as *hyper-binding* (Campbell & Davis, 2024; James et al., 2016; Strunk et al., 2017). However, even though CR modulates OAs' memory when the reinstated context is compared to a different or no context, it should be impaired when the comparison between context conditions challenges the specificity of context memory. In other words, ageing would impair mnemonic discrimination of contextual features, since these features lack fidelity in OAs, as shown by age-related reduced neural specificity (or dedifferentiation) in the PPA for scene processing (Pauley et al., 2023; Srokova et al., 2024). One recent study found a context reinstatement effect between identical and similar contexts in OAs, but lacked both a comparison group composed of YAs and a control condition with new contexts (Miao et al., 2024). In this study, we compared the effect of identical (same), visually similar (lure), and new (different) contexts on recognition memory for target and lure objects from the MST in large samples of OAs and YAs recruited online. Because we combined the methodologies used in two previous studies in a single paradigm (i.e., same/different (Racsmány et al., 2021) and same/lure (Szőllősi et al., 2023) context conditions), we first validated the effects of CR in this new design in an independent group of YAs (see pilot study 2 – validation study). Based on these preliminary results and those of previous studies (Bencze et al., 2024; Doss et al., 2018; Racsmány et al., 2021; Szőllősi et al., 2023), we expected the rate of old responses in YAs to be higher in the same than in the lure context conditions, replicating the result that they incidentally discriminate between similar contextual information. In contrast, we hypothesized that ageing impairs the specificity of contextual features, resulting in reduced incidental discrimination of same versus lure contexts. Therefore, we predicted a larger difference between the rate of old responses in the same and lure context conditions in YAs than in OAs. However, as contextual features still impact memory despite ageing (Craik & Schloerscheidt, 2011; Naveh-Benjamin & Craik, 1995; Park et al., 1987; Ward et al., 2017), we expected to observe a preserved CR effect between the same and different context conditions in OAs.

Methods

Ethics information

The pilot studies and the main study received approval from the Ethics Committee of the Faculty of Psychology at the University of Liège (approval #2324–090) and conform with the Declaration of Helsinki and the European General Data Protection Regulation (GDPR). Participants gave their informed consent before taking part in the study and received financial compensation according to the standard rate in the online experiment platform prolific (i.e., 9£/h, https://app.prolific.co). Because the experiment includes an incidental memory task, the exact aim could not be fully disclosed at the beginning of the study. Therefore, between the encoding and recognition tasks, participants were informed that a memory task followed, asked whether they still consented to be part in the study, and told that they were free to leave the experiment at this point if they did not.

Pilot data

Pilot 1 – Selection of experimental materials

First, because OAs were expected to be slower than YAs (Deary et al., 2010; Ebaid et al., 2017; Salthouse, 1996), we sought to determine time conditions that would allow them to perform the recognition task properly. To this aim, a pilot version of the experiment (pilot 1.a) was run among two groups of ten OAs (aged 70–80 years to maximise any effect of age on response time). While participants in the first group performed the recognition task under the same conditions as in the original study (Szőllősi et al., 2023) (i.e., 4-s deadline, inter-stimulus interval (ISI) of 500 ms), the second group performed a slower version of the task (i.e., 5-s deadline, ISI of 750 ms). The encoding conditions were identical between the two groups. At debriefing, participants were asked how fast they found the memory task (subjective speed judgements).

The procedure and inclusion criteria were the same as in the main study (see Design section). Both the proportion of non-responses and the responses to the subjective speed judgements showed that the original version of the recognition task was found too fast by OAs, whereas the slower version was well adapted to the population (see more details in the Online Supplementary Material (OSM)). Consequently, the slower version was used for OAs in subsequent studies (pilot 1.b and the main study).

Second, because mnemonic discrimination declines with age (Stark et al., 2013), the aim of pilot study 1.b was to provide an average FA rate in OAs and YAs for a large number of stimuli from the MST, to ensure that the stimuli used in subsequent studies would produce neither a ceiling effect in OAs nor a floor effect in YAs. Thus, a total of 120 pairs of target-lure objects were selected from the MST lure similarity bins 2, 3, and 4 (Stark et al., 2019). A hundred participants (i.e., 50 OAs and 50 YAs) were recruited. The stimuli were divided into two lists of 60 pairs, such that each pair was seen by 25 OAs and 25 YAs. The general procedure and inclusion criteria were the same as those of the main study (see OSM for a full description of the methods). These data allowed us to select a subset of 60 target-lure pairs from the MST lure bins 2 and 3 (therefore matching the bins used in the original study (Szőllősi et al., 2023)) that produced neither a ceiling effect in OAs (i.e., mean FA rate M=.53, SD=.13) nor a floor effect in YAs (i.e., average FA rate M=.45, SD=.15).

Pilot 2 – Validation study

Because we combined the methods used by Racsmány et al. (2021) and by Szőllősi et al. (2023) in a single paradigm, we conducted a second pilot study that aimed at validating the methodology. In other words, pilot 2 checked that the selected methodology allowed us to observe the expected context reinstatement effects in YAs, as evidenced by increased endorsement of objects presented against the same background context at study and test compared to conditions where the background context is a lure or a different context at test (with a likely increase in old responses in the lure context compared with the different context condition). To this end, 60 young participants (aged 18–30 years) were recruited online. The stimuli and procedure were identical to those of the main study (see Fig. 1 and *Design* section). Two participants were excluded from analyses because they had a discrimination score (d = Hits – FAs) equal to or below zero, therefore not exceeding chance level. To analyse the effect of Context on recognition decisions, we performed a 3 (same/lure/different context) × 2 (target/lure item) repeated-measures ANOVA on the proportions of old responses. We found significant main effects of Context, $F(2,114) = 9.34$, $p < 001$, $\eta_p^2 = .14$, and Item, $F(1,57) = 170.30$, $p < .001$, $\eta_p^2 = .74$, whereas the interaction was not significant ($p = .69$, $\eta_p^2 = .006$). These results are displayed in OSM Fig. S3. Planned comparisons revealed that stimuli presented in the same context as during encoding ($M = .63$, $SD = .13$) were on average more endorsed as old than those presented on a lure context ($M = .60$, $SD = .13$, $t = 2.41$, $p < .01$, Cohen's $d = .31$). Stimuli presented in a different context ($M = .56$, $SD = 14$) were less judged as old than those presented in a lure context ($t = 2.25$, $p < .05$, $d = .29$), and than those presented in the same context ($t = 3.89$, $p < .001$, $d = .51$). We note that all comparisons remained significant when applying Holm's correction for post hoc tests (Holm, 1979) (all $ps < .05$). Pilot 2 thus validated the methodology in YAs.

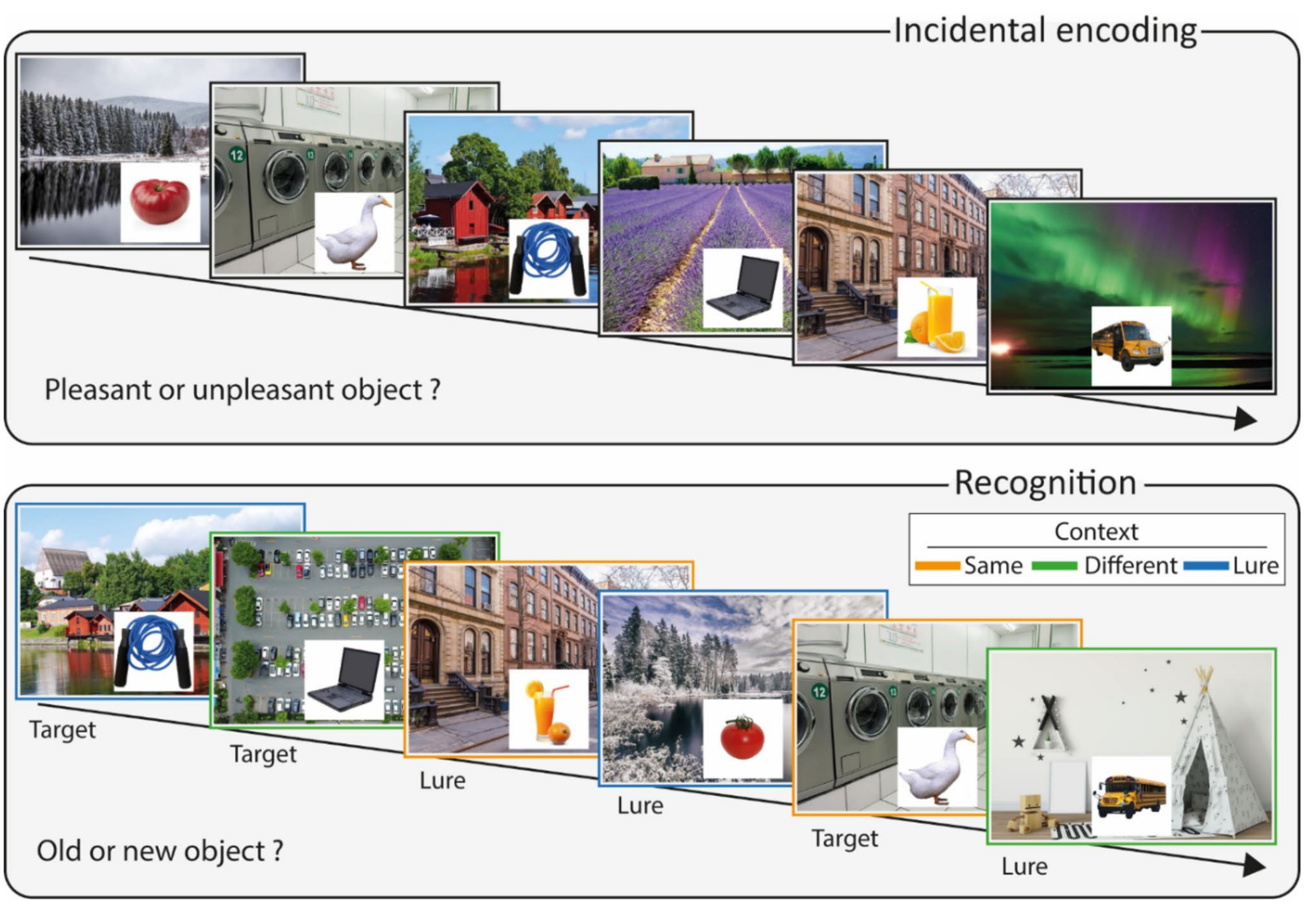

Fig. 1 Experimental design. In the incidental encoding task, participants judged objects placed against scene backgrounds as either pleasant or unpleasant. During the recognition task, they were asked to give old/new answers to target and lure objects presented against the same, a new (different), or a visually similar (lure) scene background. In both tasks, they were explicitly told that their responses must relate to the objects only

Table 1 Summary of pilot studies

	Aim	Methodology	Samples
Pilot 1.a	Determine time conditions for OAs in the recognition memory task	Comparison of two versions of the experiment with different time conditions	$N=20$ OAs
Pilot 1.b	Select object stimuli from the MST	Comparison of two versions of the experiment with different object stimuli	$N=100$ (50 OAs, 50 YAs)
Pilot 2	Validation of the experimental design in YAs	Effect of same, lure, and different context conditions on rates of old responses	$N=60$ YAs
Pilot 3	Validation of the visual discrimination task	Visual discrimination task completed by different age groups	$N=45$ (three age groups)

OA older adult; *YA* younger adult.

Pilot 3 – Visual discrimination task

Given that the specificity of memory for context may decrease in ageing partly because of poor visual discrimination of complex stimuli (Gellersen et al., 2021, 2023), such discrimination was evaluated in the main study. Pilot study 3 aimed at validating the task that was used to assess participants' visual discrimination abilities. Twenty-five pairs of similar scene images were selected from a larger pool of validated image pairs (Szőllősi et al., 2023) in order to be comparable to the scene images used as context during the recognition memory task. The objective of pilot study 3 was to ensure that the selected material would allow the task to be performed by both YAs and OAs without any ceiling or floor effects. We therefore recruited three groups of 15 participants, aged respectively 18–30, 65–74, and 75–85 years. Two groups of OAs were recruited to maximise any effect of age (see OSM for detailed demographic data). In the visual discrimination task, participants are first presented with one of the images of the pair for 4 s and instructed to pay attention to it. The image in a pair that becomes the target is randomly selected at each trial, and trial order is randomised. After a 500-ms fixation cross, the two images of the pair are presented, and participants are instructed to decide which of them matches the previous one by pressing the relevant keyboard buttons (i.e., "F" and "K" for left and right, respectively). Maximum response time was 8 s, and two trials were separated by a 1,000-ms fixation cross. The results showed that the task was performed successfully by the three age groups without producing floor or ceiling effects (the mean accuracy of each of the three age groups was between 88 and 92% correct; see OSM for a detailed description of the results). This task was therefore used to measure visual discrimination abilities for scenes (i.e., material comparable to that used as backgrounds in the memory task) (Table 1).

Participants

A group of YAs (aged from 18 to 30 years) and a group of OAs (aged from 65 to 80 years) were recruited online via the behavioural research platform prolific. To determine the adequate sample size, we conducted a power analysis using G-power. In the present study, we expected the effect of context on recognition decisions to be modulated by age group. More specifically, we expected the difference between the same and lure context conditions to be larger in YAs than in OAs. Because we had no prior data informing us about the size of this potential Age × Context interaction effect, we estimated the required sample size using a hypothetical small to moderate effect size of $f=0.15$, which is a conservative estimation based on the effect sizes reported in previous studies on memory specificity in ageing (Acevedo-Molina et al., 2020; Mutter & Asriel, 2018; Sacripante et al., 2019; Whatley & Castel, 2022). Using this effect size and $\alpha=.05$ in a 3 × 2 (same/lure/different context × older/younger groups) mixed design, a total sample size of $N=116$ is required to achieve a power of 95%.[1] However, based on the effect size observed in the validation study (i.e., $d=.317$) and with $\alpha=.05$, a minimal sample size of $N=110$ is required to achieve a power of 95% to detect the difference between same and lure context conditions in Yas.[2] Therefore, we recruited 220 participants (i.e., 110 participants per group). Demographic data are detailed in Table 2.

Inclusion criteria:

- Age: 18–30 or 65–80 years
- Normal or corrected-to-normal vision
- Fluent English speaker
- No history of neurological or psychiatric condition (including mild cognitive impairment and neurodivergence)
- No ongoing mental illness (e.g., depressive disorders)
- No more than 500 prior studies completed on Prolific (as recommended by Greene & Naveh-Benjamin, 2022b)

[1] We note that this analysis was run using the "as in G-power 3" parameter, while recent studies.
recommend using non-default options (e.g., Thibault et al., 2024).

[2] Using a one-tailed t-test.

Table 2 Demographic data for younger and older adults in the main experiment

	Age Mean (SD) [range]	Education (years) Mean (SD) [range]	Gender Females (%)	Ethnicity White/Black/ Mixed/Asian/Other
Older adults	69.49 (3.92) [64–80]	15.95 (3.42) [6–25]	60 (54.54)	102/4/2/0/2
Younger adults	25.36 (3.28) [19–34]	16.02 (2.52) [3–22]	57 (51.81)	60/20/10/14/6

Exclusion criteria:

- Participants with chance-level performance, that is, discrimination score (d = Hits – FAs) below or equal to zero. Twenty-three participants were excluded based on this criterion and replaced to reach the target sample size.
- Participants who would guess the aim of the study as revealed by the debriefing question. This included participants who mentioned (1) that context images changed between the initial presentation and memory task, (2) that some context images were visually similar versions of the original images, and (3) that this manipulation is intended to modulate the probability of endorsing stimuli as old.

Design

Material

In both the encoding and the recognition tasks, 250 × 250 pixel objects selected from the MST (Stark et al., 2019) were placed at the bottom centre of 1,200 × 800 pixel scene images (see Fig. 1). The object pictures were the items, and the scene images were the contexts. The encoding phase included 120 item-context pairs. During the recognition memory task, 120 object-scene pairs were presented, half of which included a target object, whereas the other half included a lure object. A third of the target and a third of the lure objects (i.e., 20) were placed against the same contexts as at encoding, a third against lure contexts, and a third against different contexts (Fig. 1). The object stimuli were those selected in pilot study 1.b.

As in the pilot and validation studies, we used scene images from previous studies (Racsmány et al., 2021; Szőllősi et al., 2023). Lure contexts were scenes visually similar to the scenes against which the corresponding object was placed during the encoding phase, taken from a pool of scene pairs validated by Szőllősi et al. (2023). For target objects, the same/lure background context was always the same scene/visually similar scene that was associated with the same object at encoding. For lure objects, it was the same scene/visually similar scene that was associated with the corresponding object (see the tomato and bus examples in Fig. 1). Both the object variable (i.e., target and lure) and context variable (i.e., same, lure, and different) were manipulated within-subjects. Object stimuli were counterbalanced across context conditions.

Procedure

During the encoding task, each stimulus was presented for 4 s with an ISI of 1 s. Participants were asked to judge each object as either pleasant or unpleasant using keyboard buttons ("F" and "K" keys, respectively). Because we were not interested in age differences in overall performance or speed, the timing of the recognition task was different between YAs and OAs. This mainly aimed to provide enough time for OAs to perform the task properly (see pilot study 1.a). For YAs, the stimuli were presented for 4 s at the maximum and separated by 500 ms of ISI as in the original study, whereas for OAs, stimuli were presented for 5 s maximum and separated by 750 ms of ISI. Participants were instructed to judge the objects as old or new by using the "O" and "N" keys, respectively. They were informed that some objects would be visually similar to, but not exactly the same as, objects that they had seen before and were instructed to only select "old" when the object was the exact repetition of a previously seen item. Following each recognition decision, they were asked how confident in their response they feel, from 1 "not at all sure" to 6 "very sure" using keyboard buttons. As in the original study, there was a 90-s break between encoding and recognition during which participants completed a practice session of the old/new judgement and confidence rating (i.e., they were presented with labels and asked to press the corresponding button). In both the encoding and recognition tasks, participants were explicitly told that their responses had to relate to the objects specifically. Finally, participants performed the visual discrimination task with the 25 scene pairs validated in pilot study 3. In this task, a scene image was first presented for 4 s, and participants were instructed to pay attention to it. After a 500-ms delay, a pair of scene images was presented, one being the same as the one presented just before and the other being a similar lure scene, and participants were instructed to decide which of them matched the previous one. Response keys were the same as in the pleasant/unpleasant task (i.e., "F" for left, and "K" for right). Maximum response time was 8 s, and two trials were separated by a fixation cross displayed for 1 s. Trial order was randomised and the image in a pair that became the target was randomly selected at each trial (see pilot study 3 in OSM for full details of this task).

Debriefing and level of education

Because the experiment was conducted online, participants were asked whether they performed the experiment seriously (they were reminded that all responses are anonymous, and that their answer would not affect their compensation). In addition, they were asked what they thought the aim of the experiment was. None of the participants met the exclusion criteria related to the debriefing questions. Finally, they were asked how many years of education they successfully completed from primary school to their highest degree.

Analyses

In YAs, we expected to replicate the results of the validation study: an increase in old responses to both targets and lures in the same context condition compared to the lure and different context conditions. In contrast, we hypothesized that the difference between lure and same contexts would be reduced (if not abolished) in OAs. Therefore, we conducted mixed (within-between) analysis of variance (ANOVA) with the factors context (Same/Lure/Different), age (YAs/OAs), and item (Target/Lure) on the rate of old responses. We expected to find a context × age group interaction such that the difference between same and lure contexts should be larger in YAs than in OAs. Although prior research has shown similar effects of context on target and lure items in YAs (e.g., Doss et al., 2018), whether the same pattern would be found for OAs is unknown. Thus, we did not expect to find a context x item interaction but included the item variable in the analysis to allow for any age effect to differ between targets and lures. A similar analysis was conducted for confidence ratings: context and item were included as within-subject factors and age as a between-subject factors. We expected to find a main effect of item such that confidence ratings are higher for targets than for lures. We also expected to observe a main effect of context such that confidence ratings would be higher for same contexts than for lure contexts, and higher for lure contexts than for different contexts.

Results

Main research question

First, we conducted a mixed (within-between) analysis of variance (ANOVA) with factors Context (Same/Lure/Different), Age group (YAs/OAs), and Item (Target/Lure) on the rate of old responses. We found a significant main effect of Item, $F(1,218) = 592.68$, $p < .001$, $\eta^2_p = .73$. Targets ($M = .78$, $SD = .17$) were on average more frequently judged as old than lures ($M = .50$, $SD = .20$). The main effect of Age group was also significant, $F(1,218) = 37.60$, $p < .001$, $\eta^2_p = .14$, indicating that older adults endorsed stimuli as old more often than younger adults did. The main effect of Context was significant as well, $F(2,436) = 47.12$, $p < .001$, $\eta^2_p = .17$. Planned comparisons revealed that the objects presented on the same background scene at encoding and test were on average more often judged as old than those presented on a lure background, $t(218) = 4.79$, $p < .001$, $d = 0.32$ and those presented on a new background, $t(218) = 8.04$, $p < .001$, $d = 0.54$. The objects presented on a lure background were also more frequently endorsed as old than those presented on a new background, $t(218) = 6.08$, $p < .001$, $d = .41$. The interaction between Item and Context, $p = .33$, $\eta^2\mathrm{p} = .005$, between Context and Age group, $p = .86$, $\eta^2\mathrm{p} = .001$, and between Item and Group, $p = .30$, $\eta^2\mathrm{p} = .005$, were not significant. The three-way interaction was also non-significant, $p = .99$, $\eta^2\mathrm{p} < .001$. A paired-sample t-test confirmed that older adults judged the objects presented with the same background at encoding and test as old more frequently than those presented with a lure background, $t(218) = 2.94$, $p < .01$, $d = 0.29$. These results are illustrated in Fig. 2a.

Confidence ratings

We conducted a mixed (within-between) analysis of variance (ANOVA) with factors context (Same/Lure/Different), age (YAs/OAs), and item (Target/Lure) on the confidence ratings for old responses. We found a significant main effect of Item, $F(1,210) = 229.68$, $p < .001$, $\eta^2_p = .52$. Confidence ratings were on average higher for targets ($M = 5.23$, $SD = 0.84$) than for lures ($M = 4.91$, $SD = 0.91$). The main effect of Context was also significant, $F(2,420) = 21.16$, $p < .001$, $\eta^2_p = .09$. Planned comparisons revealed that confidence ratings to old responses were higher in the same context condition than in the lure context condition, $t(210) = 2.95$, $p < .01$, and in the different context condition, $t(210) = 5.56$, $p < .001$. Confidence ratings were also higher in the lure context condition than in the different context condition, $t(210) = 4.01$, $p < .001$. The main effect of Age group was not significant, $p = 1$, $\eta^2_p < .001$. There was no Context x Item, Context x Age group, and Item x Age group interaction (all ps > .36), and no three-way interaction ($p = .59$). These results are illustrated in Fig. 2b.

Visual discrimination scores

We compared the accuracy in the visual discrimination task between younger and older adults and found no significant difference, $t(218) = -0.61$, $p = .53$. The accuracy of

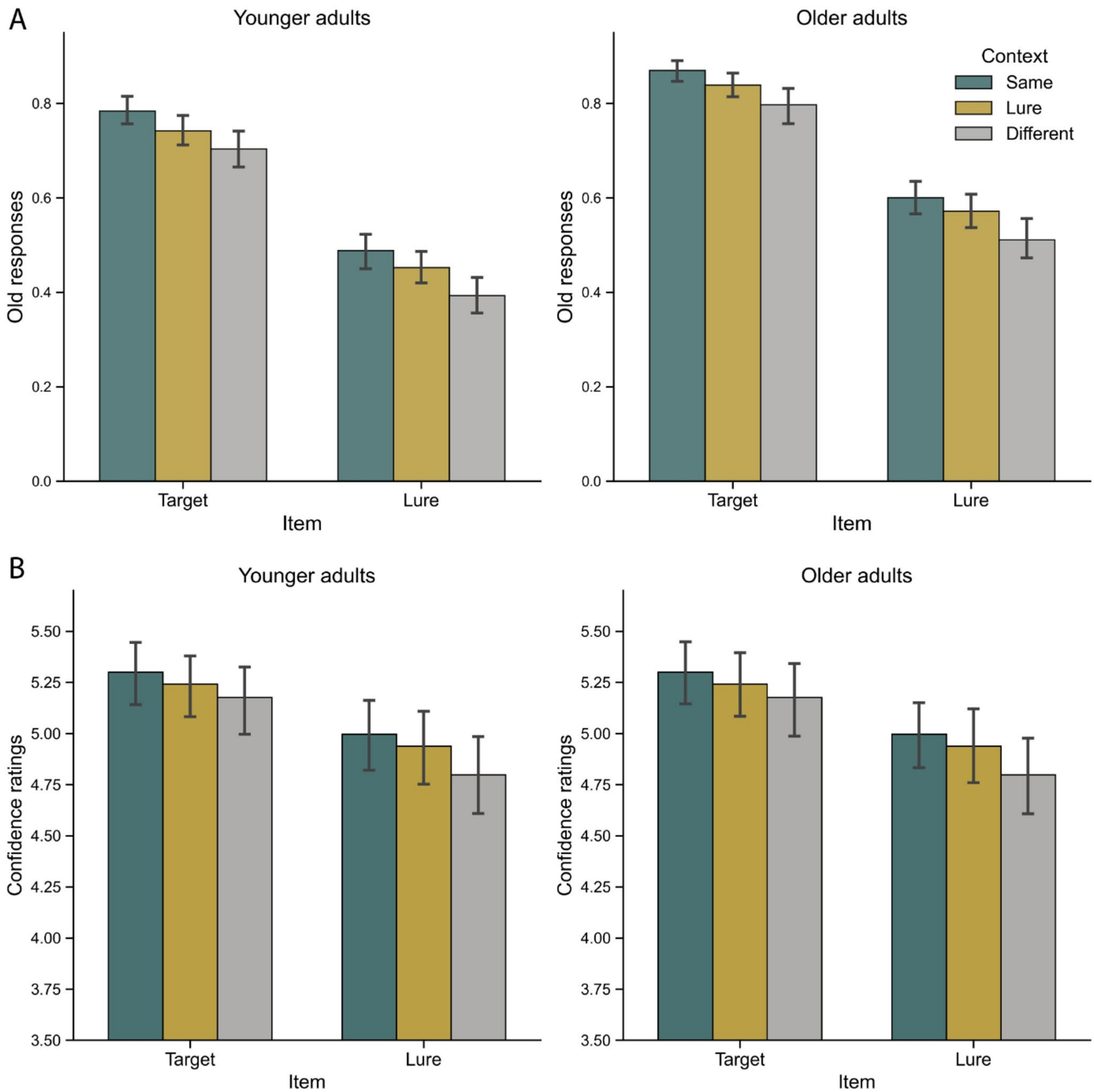

Fig. 2 Results of the main experiment. **A**. Proportion of old responses to targets and lures as a function of Context and Age group. **B**. Confidence ratings to targets and lures as a function of Context and Age group. The figure shows means and 95% confidence intervals

both OAs ($M = 91.52\%$, $SD = 11.37$) and YAs ($M = 92.47\%$, $SD = 11.31$) was relatively high. Education was also matched between age groups, $t(218) = -0.18$, $p = .85$. Therefore, none of these variables was likely to explain any age-related differences in the present study.

Exploratory analyses

Because we found a main effect of Age group on the proportions of old responses, we explored signal detection theory metrics of recognition memory. These included discrimination $d' = z(\text{Hits}) - z(\text{FAs})$, decision criteria $c = -0.5 * (z(\text{Hits}) + z(\text{FAs}))$, and response bias $\beta = \exp(c * d')$. There was no age difference in memory discrimination ($p = .83$). In contrast, OAs had both a higher decision criterion index, $t(218) = -5.77$, $p < .001$, Cohen's $d = 0.77$, and a higher response bias index, $t(218) = -5.42$, $p < .001$, $d = 0.73$, than YAs (see OSM and Fig. S1 for details). These results confirmed that memory decisions were more liberal in older than in younger adults in this study.

Discussion

In this study, we aimed to test whether typical ageing impairs the specificity of contextual features implicitly integrated into episodic memory traces. Older adults are generally impaired in direct tests of context memory such as source memory (Mitchell & Johnson, 2009; Spencer & Raz, 1995). In contrast, indirect modulations of memory by contextual elements, such as in the CR paradigm, is preserved in typical ageing (Craik & Schloerscheidt, 2011; Naveh-Benjamin & Craik, 1995; Park et al., 1987; Symeonidou et al., 2026; Ward et al., 2017). A recent study showed that in younger adults, the reinstatement of same versus similar lure background scenes produced differential effects on recognition memory decisions (Szőllősi et al., 2023). This registered-report aimed to test the hypothesis that this indirect contextual modulation is reduced in older adults given the age-related decline in memory specificity (Greene & Naveh-Benjamin, 2023; Grilli & Sheldon, 2022). Therefore, we used a CR paradigm to compare the effect of identical (same), visually similar (lure), and new (different) background scene contexts on mnemonic discrimination for focal objects in YAs and OAs.

First, we found that the reinstatement of the original background scene contexts increased old responses to both target and lure objects, confirming that the CR manipulation was effective in the present study (Doss et al., 2018; Racsmány et al., 2021). Specifically, objects presented with the same background at encoding and test were more often judged as old than those presented on a lure background, replicating the finding that slight visual differences between encoding and recognition contexts differentially influence recognition decisions (Szőllősi et al., 2023). In addition, we found that old responses increased gradually between different, lure, and same background conditions. This novel finding is in line with the Encoding Specificity Hypothesis according to which the perceptual overlap between encoding and retrieval inputs influences the likelihood of reactivating a memory trace (Tulving & Thomson, 1973; see also Murnane & Phelps, 1993). Contrary to our hypothesis, this gradual effect of context was present in both age groups. These results are unlikely to be explained by a lack of statistical power. Rather, it constitutes evidence against our hypothesis and suggests that OAs are able to integrate detailed contextual information as younger participants do, and that these features impact decisions on an explicit mnemonic discrimination task.

These findings may seem at odds with the well-established view that the specificity of memory representations declines with typical ageing (Greene & Naveh-Benjamin, 2023; Grilli & Sheldon, 2022). One previous study reported consistent results: same and lure background scenes produced differential effects on recognition decisions in OAs (Miao et al., 2024), but in this study, the instructions at encoding oriented towards object-scene associations. In our paradigm, in contrast, contextual information was task irrelevant both at encoding and during the recognition memory test, consistent with the definition of context as unattended information presented alongside attended features (Hayes et al., 2007). Although we cannot ascertain that context encoding in the present study was unintentional as participants may have used strategies, previous studies have shown that CR effects are at least partially implicit (Doss et al., 2018; Hayes et al., 2007). Our study thus extends these results by showing that OAs encode highly detailed contextual features as YAs do, which can be observed when examining context memory indirectly. Previous studies have shown that controlled retrieval processes are more impaired in typical ageing compared with automatic processes (Ikier et al., 2008; Jennings & Jacoby, 1993; Kılıç et al., 2017), leading to larger age-related decline in recall than in recognition memory tests (for a recent meta-analysis, see Rhodes et al., 2019). It was also reported that OAs initially encode detailed memory representations but are less likely to engage in deep elaboration at retrieval, limiting their access to these representations (Greene & Naveh-Benjamin, 2022a). Unlike in direct tests of context memory, the indirect modulation of mnemonic discrimination by contextual information in the present study required neither controlled processes nor deep elaboration at retrieval. Therefore, this indirect paradigm allowed us to evidence that typically ageing individuals encode highly detailed contextual information in episodic memory.

As predicted, the confidence ratings of old responses were higher for target than for lure objects, and increased gradually between the different, lure, and same background context conditions. Interestingly, the pattern of confidence ratings was similar between YAs and OAs, suggesting that the two groups relied on the same memory processes. Old responses were on average associated with relatively high confidence ($M = 5.07$, $SD = 0.89$), which is a marker of recollection (Yonelinas, 2002). However, the confidence of old responses to both targets and lures varied with context conditions. As for the rates of old responses, the gradual effect of context is a new finding and is consistent with the Encoding Specificity Hypothesis (Tulving & Thomson, 1973). Recollection is more impaired than familiarity in typical ageing (Alghamdi & Rugg, 2020; Koen & Yonelinas, 2016), and age-related context memory deficits can be reduced when task manipulations put more emphasis on familiarity-based recognition memory (Bastin et al., 2013). Therefore, the preserved effect of context in older adults in the present study might be explained by familiarity processes, in line with the hypothesis that CR elicits a fluency signal that artificially increases familiarity for the focal object (Gardette et al., 2025). Future studies should employ a proper process dissociation procedure combined with a CR paradigm to answer this question. Furthermore, future research should examine the type of memory traces that contribute to CR effects in OAs. One may expect that they rely on gist traces, which are preserved in typical ageing (Greene & Naveh-Benjamin, 2023; Grilli & Sheldon, 2022). Context recollection, the vivid reinstatement of contextual details associated with target items, could also serve this role (as opposed to target recollection; Brainerd et al., 2022). Examining memory decisions in the CR paradigm using the conjoint recognition model could provide useful insights into this question, as it allows disentangling the contributions of verbatim and gist memory traces to recognition memory (Brainerd et al., 1999, 2004, 2022).

One limitation of this study is that because it was conducted online, there is no standard assessment of neuropsychological abilities (e.g., MoCA) that would inform us on the sample representativity. We used the number of previous studies completed online as a criterion to exclude expert participants, and education level was matched between age groups. However, we cannot rule out the possibility that the OAs recruited in the present study are "super-agers", individuals who maintain a high level of function and activity from midlife to advanced age (Powell et al., 2023). Age effects were observed on SDT metrics, namely criteria and bias indexes, indicating that OAs exhibited an *old* response bias compared with YAs, leading to increased hits and false-alarm rates. Consistent with previous work reporting more liberal responses in recognition memory in ageing (Fraundorf et al., 2019), this finding indicates that although the effect of context was not modulated by age in the present study, the two age groups showed distinct profiles of memory retrieval.

Taken together, the findings of the present study indicate that OAs integrate highly detailed contextual information, which can indirectly influence their mnemonic discrimination decisions, as for younger adults. In contrast with the specificity impairment in typical ageing, these results add to the recent view that OAs can adaptively draw upon preserved aspects of episodic memory in daily life situations (Castel, 2024; Greene & Naveh-Benjamin, 2024).

Supplementary Information The online version contains supplementary material available at https://doi.org/10.3758/s13423-026-02971-y.

Author contributions JG: Conceptualization, investigation, formal analysis, visualization, writing – original draft.

AS: Methodology, writing – review and editing.

DB: Methodology, writing – review and editing.

MR: Methodology, writing – review and editing.

CB: Conceptualization, funding acquisition, supervision, writing – review and editing.

Funding This work was supported by the SAO/Fondation Recherche Alzheimer (grants 2023–0010 and 2025–0020), the University of Liège (grant FSR2023-SS-2023/08), the F.R.S-FNRS, and Wallonie-Bruxelles International (WBI). M.R., Á.S., and D.B. were supported by the NAP2022-I-2/2022 Hungarian Brain Research Program 3.0 Research Grant and by the Ministry of Innovation and Technology of Hungary from the National Research, Development and Innovation Fund, financed under the NKFIH K146237 funding scheme. Furthermore, Á.S. was supported by the Bolyai János Research Scholarship of the Hungarian Academy of Sciences.

Data availability Raw data and materials can be viewed at: https://osf.io/2dks9/?view_only=8e630929a26a41d19d98536239edbb27

Code availability Codes can be viewed at: https://osf.io/2dks9/?view_only=8e630929a26a41d19d98536239edbb27

Declarations

Conflicts of interest/Competing interests The authors declare no conflicts of interest or competing interests.

Ethics approval The pilot studies and the experimental study received approval from the Ethics Committee of the Faculty of Psychology at the University of Liège (approval #2324–090) and conform with the Declaration of Helsinki and the European General Data Protection Regulation (GDPR).

Consent to participate Participants gave their informed consent before taking part in the study.

Consent for publication Participants gave their informed consent for the inclusion of their anonymised data in a scientific publication.

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