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Sometimes it helps to be taken out of context: Memory for objects in scenes

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ABSTRACT

It is well known that humans demonstrate massive and surprisingly rich recognition memory for objects and/or scenes and that context typically aids retrieval of episodic memories. However, when we combine picture memory for 100 objects with the context in the form of a background scene, we find that irrelevant contexts lead to substantial impairments of object memory. Twelve experiments used a standard long-term, picture memory paradigm. Backgrounds could be semantically consistent or inconsistent scenes or simple arrays of objects. In all cases, the target object to be remembered was clearly marked by an outline box. Backgrounds were always known to be irrelevant, but, nevertheless, significantly reduced old/new discrimination for target objects. Interference from the scene was apparently unavoidable, suggesting that the seemingly effortless encoding that makes it easy to store scenes into memory, makes it hard to avoid interference with the encoding and recognition of objects placed in or on those scenes.

Humans are very good at remembering large numbers of pictures. These can be scenes (Hollingworth, 2004; Konkle et al., 2010; Shepard, 1967) or individual objects (Brady, Konkle, Alvarez, & Oliva, 2008; Standing, 1973; Standing et al., 1970). As one example, Brady et al. (2008) report that, after memorizing 2500 objects over the course of 5 h, observers were able to select the studied object with great accuracy from an old/new pair of images. They were 92% correct with a foil from a novel category, 88% with a foil from the same basic category, and 87% with a foil that was the same memorized object in a different state (e.g., toaster oven, open vs. closed). Performance declines, though it can remain impressive, when the testing procedure is changed from two alternative forced choice to an old/new recognition task (Cunningham et al., 2015).

In massive memory experiments, observers are typically asked to remember either objects or scenes independently. In other contexts, it has been shown that objects and the scenes they are part of are processed interactively, not in isolation (Davenport & Potter, 2004) and that contextual information enhances object identification (Biederman et al., 1982; Boyce & Pollatsek, 1992; Palmer, 1975). In the work reported here, we ask about the fate of massive recognition memory for objects when they are embedded within scenes (e.g., Was this knife present at the crime scene?).

The term "context" in psychological research over the past century has been defined in different ways but a usefully broad definition is the one given by Tulving (1985) who calls it the "setting" or "cognitive environment" in which a memory item is presented. The effects of context have been explored for both verbal and visual material and in both semantic and episodic memory. In semantic memory, the effects of context are consistently beneficial (e.g., verbal recognition of words using sentence context or other words; Meyer & Schvaneveldt, 1976; Tulving & Gold, 1963), whilst episodic memory is typically improved if the context at the time of encoding is repeated at the time of recall. The encoding specificity principle (Tulving & Thomson, 1973) in long-term memory literature maintains that the better the match between study and retrieval contexts, the better the memory

for studied items, even if the context is seemingly irrelevant to the studied item. There is evidence that global, environmental context (i.e., the surrounding in which the material was encoded) plays a small but consistently positive role in recall for verbal material (Eich, 1985; Godden & Baddeley, 1975; Smith et al., 1978; Smith & Vela, 2001). The positive effects of context reinstatement during tests are also observed in recognition memory tasks (Hanczakowski et al., 2015). In memory for verbal material, a *decreased* memory for items presented in *different* contexts at study and test phases is called the "context shift decrement". The decrement has been observed when the change in context is in more local surrounding verbal context (Humphreys, 1976; Light & Carter-Sobell, 1970; Tulving & Osler, 1968); in font format and/or orientation (Graf & Ryan, 1990); in foreground and background colour (Dougal & Rotello, 1999; Mori & Graf, 1996); or in rich vs. simple background context (Murnane et al., 1999).

In episodic memory for faces, global and local contextual effects have been studied in several conditions. Context has been defined as an accompanying face (Bower & Karlin, 1974; Watkins et al., 1976; Winograd & Rivers-Bulkeley, 1977); the background on which the face is portrayed (Beales & Parkin, 1984: Davies & Milne, 1982; Memon & Bruce, 1983; Parkin & Hayward, 1983; Thomson et al., 1982); the environment of testing (Davies & Milne, 1982); clothing (Brutsche et al., 1981; Thomson et al., 1982); and the presence or absence of guided instructions (Davies & Milne, 1982; Geiselman, 1984; Loftus et al., 1983: Malpass & Devine, 1981). Overall, the determining factor for finding contextual effects (positive or negative) appears to be the degree of similarity between context at encoding to that at the test phase.

In studies of objects in scenes, the general finding is that scene context supports object memory (Hayes et al., 2007; Hollingworth & Henderson, 2002; Hollingworth, 2006, 2009; Park et al., 1984; Park et al., 1987; Silva et al., 2006). For instance, Hollingworth (2006) found that the presence of a scene during encoding gives a boost to recall of the identity and pose of target objects when the objects are presented in the same scene during recall compared to a blank background or when another scene is viewed between encoding and the test (his Exp. 2). Castelhano and Henderson (2005) found that automatic encoding of objects in scenes occurs even without explicit instruction (but see Nakashima & Yokosawa, 2011).

On the other hand, there are situations in which context has a negative effect on memory. There is some evidence of a context shift decrement when the stimuli are images of objects (Hayes et al., 2007). Interference effects have not been given much attention in the recent examinations of large-capacity, visual long-term memory. It can be assumed that extra, irrelevant information in the scene could cause some degree of interference with long-term memory, if the context captured attention or otherwise used up resources that could have been devoted to encoding the target. Presumably, such effects would be reduced if attention was guided to the relevant memory targets (e.g., by cueing). Proactive interference (Barnes and Underwood 1959) might also reduce memory for an object in a scene if there was competition between a previously learned association (that lamp is in the dining room) and a subsequent association (the lamp is in the living room). Proactive interference increases with increased overlap of context between past and current state.

In our previous work, we observed a different situation in which context disrupted performance (Evans et al., 2011). Our participants were looking for target objects, defined by their category. They were cued for the target category on each trial (e.g., "animal"). A set of categories would be relevant for an entire block of trials (e.g., beach, mountain, animal, vehicle). Observers can reliably detect the presence of a categorical target in 20 ms. However, performance was strongly impaired at those durations if two targets of different categories were present on the same trial. For example, observers might be very good at detecting either a beach or an animal in a scene in 20 ms, but, if stimulus was a scene of a beach with an animal, performance was very poor at those brief durations. Of course, with more sustained viewing, people could process both animal and beach but the interference at brief durations suggests a form of interference in early coding that might disrupt encoding or recall from episodic memory.

In this paper, we bring together the study of context with the study of high capacity memory of objects and scenes. A characteristic of most previous work on context effects, as reviewed above, is that

observers hold relatively small numbers of target in memory, far fewer than the 100 that we will use here. Here, we look systematically at the effects of context when 100 items are encoded into memory. The effects of storing 100 objects in 100 contexts might or might not be the same as the effects of learning a set of words in one room and recalling them in another (Godden & Baddeley, 1975). Note that learning many objects in many contexts is a realistic description of daily life. As we will show, with this more substantial picture memory load, the effects of context are generally negative (i.e., context decrement effect). In our experiments, at least, a background context – even an appropriate context – at encoding seems to clutter and/or degrade the target representation rather than providing additional cues to recognition at the time of the test. Best performance is actually obtained when we separate the memory for target items from their learning context. We do not argue that prior demonstrations of supportive context effects were wrong. Rather, we are describing a situation in which those classic benefits are not available. Understanding when context aids and when it interferes helps us to better understand the encoding process and to identify situations under which problems like false memories might arise.

General methods and materials

Participants, stimuli & apparatus

One hundred and fifty-six adults (114 females, aged 18–54) gave informed consent and participated in 12 experiments. Each observer took part in only one experiment. Each passed the Ishihara colour blindness test and had normal or corrected to normal vision. In all the experiments conducted, we used the standard old/new visual recognition memory paradigm. To assess statistical power, we used our previous published work (Evans et al. 2011). The same paradigm used here yielded an estimated effect size of $d =$ 1.74 (Cohen's d) in the prior experiment. With an effect size of 1.74, $\alpha = 0.05$ and power $= 0.95$ the minimum sample size would be 7. We set the minimum number of participants in advance to 12 per experiment. A sample size of 12 has a power of 0.99 with $d = 1.74$, $\alpha = 0.05$. In each of the experiments except Exp. 10 (where there were 24 participants because we used a within-subject design and

cut the number of trials per condition in half) we used different groups of 12 participants. We chose a between-subject design for these experiments because we wanted to be able to use the same stimulus set across experiments.

Stimuli consisted of 950 distinct, coloured images of whole scenes and single objects gathered using internet searches with Google Image Search or taken from Aude Oliva's Massive Visual Memory Stimuli database (http://cvcl.mit.edu/MM/stimuli. html, see Figure 1). The scenes were 550 mostly indoor scenes (kitchen, living room, bathroom, bedroom, dining room, entrance hall, study) with some outdoor scenes (patios and gardens). Congruent objects (150 in total, appliances, chairs, sofas, beds, cabinets, desks, lamps, chandeliers, tables, ornaments) were extracted from the scenes and were the same size when presented in isolation or in scenes or arrays. The target objects used in Experiment 1 were the same set used in Experiments 2 and 3 and were the same objects that were embedded in scenes in Experiments 5, 6, 7, 10, 11, and 12. Incongruent objects were taken from semantically inconsistent categories (150 in total: motorbikes, bicycles, tricycles, carts, lawnmowers, kayaks, anchors, ATVs, machinery, and scooters). Thus, the incongruent set of objects were an entirely separate set of objects from the congruent set. They were incongruent with the scene backgrounds in which they were embedded, for example, a kayak in a living room.

The scene stimuli and object arrays subtended approximately 13° × 13° of visual angle at the approximately 57 cm viewing distance. Single items in isolation were presented at the same size as they would have been in the scenes or arrays. Stimuli were presented on a 21-inch monitor (1024 by 768 pixels, 75 Hz refresh rate, Macintosh G5 computer, OS 10.5). The experiment was controlled by Matlab 7.5.0 with Psychophysics Toolbox, v3 (Brainard, 1997; Pelli, 1997). The different types of stimuli are shown in Figure 1.

Procedure

Details of each of the 12 experiments are given below. For all experiments, there were 100 encoding stimuli and 100 test stimuli (96 encoding and test stimuli in Exp. 12). Sometimes, observers were asked to remember scenes. For pairs of scenes, either member of the
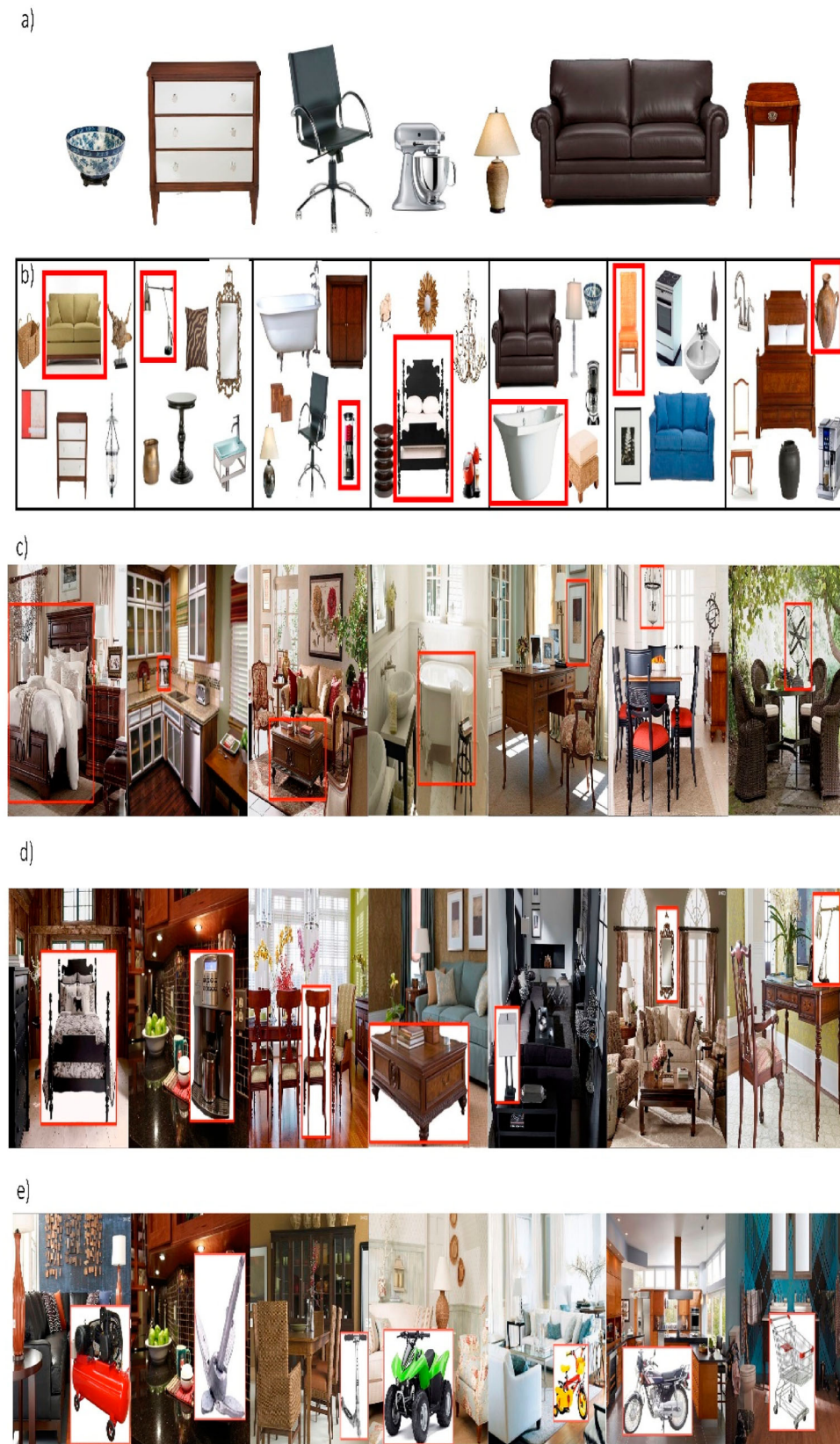
Figure 1. Examples of stimuli used in Experiments 1–12: **(a)** Single objects from categories of kitchen appliances, chairs, sofas, beds, cabinets, desks, lamps, chandeliers, tables, ornaments and extracted from scenes used in later experiment as background context. The objects in isolation were used in Experiments 1, 11, and 12. **(b)** Objects arranged in random arrays used in Experiments 2 and 3. These are the same objects used in Experiment 1. The target object to memorize and recall was always marked clearly with a salient red outline box. **(c)** Different indoor (kitchen, living room, bathroom, bedroom, dining room, entrance hall, study) and outdoor scenes used in Experiments 4–12. In Experiments 5, 6, and 10–12 the target object was clearly marked with a red salient bounding box. **(d)** Examples of stimuli used in Experiment 7. Target objects, isolated on locally white backgrounds, were embedded in the same scenes used in Experiments 4–12. **(e)** Examples of semantically incongruent to the background scene target objects (motorbikes, bicycles, tricycles, carts, lawnmowers, kayaks, anchors, ATV's, machinery, and scooters), again isolated on locally white backgrounds, embedded in scenes for Experiments 8 and 9.

pair could be randomly used as the encoding or retrieval scene (see Figure 1). In other experiments, observers were asked to remember objects. If target objects were embedded in scenes or in arrays of objects, the item to be remembered was clearly marked by a red bounding box. In some experiments, the target object could change slightly in pose or size between study and test phase. Observers were made aware of this and told to remember the object and not the state.

Each experiment followed a similar format with a study phase and immediate test phase. In the study phase, observers saw a random subset of 100 objects and/or scenes for 3 s each, one after another. Observers were told what to memorize (scene or object) in preparation for a recognition test that would follow. As noted, target objects in scenes were clearly marked with a bounding red box which means there was no need for observers to search for their targets in the scenes or arrays in either the encoding or test phase. When the object to be memorized was part of an array (stimuli in Fig. 1b) or in a scene (Fig. 1c–e), observers were explicitly told that the scene/array was task-irrelevant and that only the marked target needed to be committed to memory. Foil scenes were drawn from the same categories as the target scenes. Each object was presented once in the study phase, except in Experiment 10, where target objects were presented twice in the study phase, either in two different scene contexts (see Figure 8a) or in the same scene context (see Figure 8b) intermixed.

The test phase followed immediately after the study phase and was self-paced. At the test phase, observers saw 100 objects in isolation or embedded and clearly marked in a scene or array one after another. Fifty objects were randomly chosen *old* objects. Old objects had been seen in the study phase and now were seen again in the test phase. The remaining 50 were *new* objects (foils) that had not been previously encountered. In the testing phase, depending on the experiment, old objects could appear in the same array (Figure 3) or the same scenes as in the study phase (Figure 4), in a different scene (Figure 5), or in isolation (Figure 2). The foils appeared in new scenes or in isolation. Observers were asked to label each target as "old" or "new" by pressing the appropriate computer key. The images remained on the screen until the response was given and feedback was provided for each test trial.

Data analysis

For each experiment, d-Prime scores were computed after correcting for cells with perfect performance by adding 0.5 item to the number of hits and false alarms (Snodgrass and Corwin, 1988). We report performance in terms of d', for two reasons. First, d' is theoretically independent of an observer's bias to respond "yes" or "no". Second, it is normally distributed, unlike accuracy, which makes it more suitable for standard parametric statistics. We then performed multiple unpaired t-tests for each planned comparison and corrected for multiple comparisons using the Holm–Šídák method for multiple comparisons. Thus, the *p* values for all comparisons except Experiments 10a and 10b (this comparison was a paired sample t-test) are multiplicity adjusted *p* values (Westfall et al., 2000*)*.

Specific experiment, results, and discussion

Here we will briefly describe each of the 12 experiments, in turn. We report the results organized around four themes pertaining to visual episodic memory for objects. (1) objects alone or in arrays of items, (2) objects embedded in complex real-world scenes, (3) objects decontextualized by embedding them in different scenes at encoding at the test phase, and (4) we will examine the locus of the interaction between objects and their background scenes.
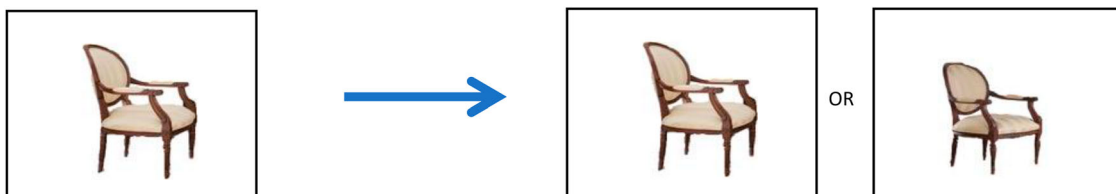

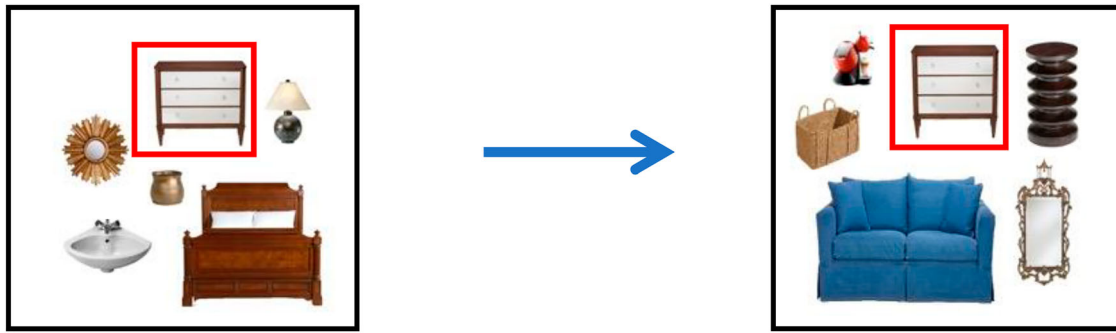**Figure 2.** Stimuli for Experiment 1.

Figure 3. Stimuli for Experiment 2.

Objects alone and in arrays

The first set of three experiments examined the effect of interference in episodic visual memory for objects by having other semantically related objects present on the screen during encoding and retrieval even if they are completely irrelevant to the task at hand. In these experiments, target objects were either presented and tested in isolation (Exp. 1) or in an array of other semantically related objects (e.g., a chair in an array of household objects, Experiments 2 and 3).

Experiment 1 was the baseline experiment. Observer were shown 100 objects, one at a time and asked to remember them. At the test phase, they were shown 50 old objects, presented during the study phase, and 50 new objects (i.e., foils). Objects at the test phase could vary slightly in size and pose compared to study (see Figure 2). On average, observers produced 14% false alarm errors (FA) and 86% true positive (HIT) responses; d″ = 2.27 (s.e.m. 0.12).

Experiment 2 used the same set of objects but presented them in an array of other objects. Observers were shown arrays of objects and asked to remember only the target object clearly marked by a bounding red rectangle. There were 100 objects, each presented within a novel unstructured array of five other objects (see Figure 3). Array objects were semantically related to the target object (e.g., a chair in an array of household objects). In the test phase, observers saw 50 old objects from the study phase, presented in the same arrays as during the study phase and 50 new objects in new arrays. On average, observers produced 21% FA and 78% HIT responses; d′= 1.71 (s.e.m. 0.23).

Note that placing a target object in an otherwise irrelevant array significantly reduced performance relative to Experiment 1 (t(22) = 2.44, p = 0.023, Cohen's d = 1.04). Memory performance decreased even when the target was presented in exactly the same unstructured array at the test phase (Exp. 2 d′ = 1.71). The irrelevant information at encoding and/or retrieval apparently produced interference that reduced the performance relative to objects presented in isolation (this is documented in Table 1). This effect does not reach significance if corrected for multiple comparisons. That said, it is worth noting that *all* of the conditions with context are worse than the *no context* baseline condition (Exp. 1). Given this pattern of results, the difference between Exp. 1 and Exp. 2 seems unlikely to be a false positive, even if our many conditions raise the bar for statistical significance in the face of potential
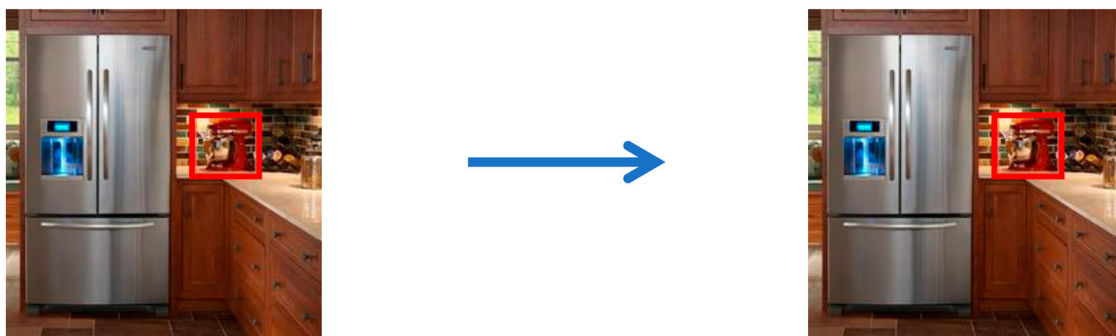

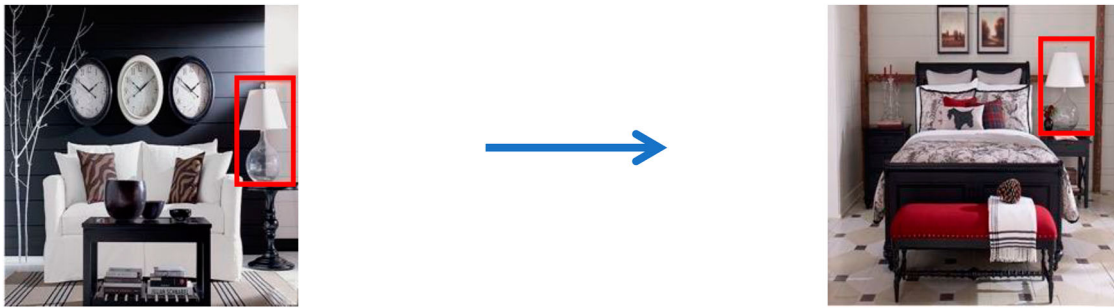**Figure 4.** Experiment 5: memorize only the object in the red box.

Figure 5. Experiment 6: the study object is presented in a new scene at the test phase.

multiple comparisons. Certainly, the repeated context at study and test phases did not help.

In Exp. 3, the unstructured array of items around the target object changed between study and test phases. The experiment was identical to Experiment 2, except that the arrays on "old" trials at the test were novel. Recall, however, that the target was clearly marked by a red box at encoding and testing. There were 28% FA and 75% HIT responses; d'= 1.38 (s.e.m. 0.17).

Performance dropped somewhat relative to Exp. 2 (Exp. 3 d' = 1.38 vs. Exp. 2, d' = 1.71) but this change was not significant compared to studying and testing in the same array (Exp. 2 vs. Exp. 3, t(22) = 1.15, p = 0.262). One would expect more of a drop in performance in comparison to Experiment 2 assuming loss of context reinstatement effect (Tulving & Thomson, 1973) even when the context is task irrelevant arrays. Accuracy in Exp. 3 was significantly worse than in the baseline, Exp. 1, when objects were presented in isolation (Exp. 1 vs. Exp. 3, Table 1). Thus, in Experiment 3, when the targets were placed

Table 1. Results of multiple t-test comparison between results of Experiment 1 and each of Experiments 2–9.

Experiment	Study phase	Corrected t-tests
1 Isolated objects d' = 2.27	**2 Objects in arrays (test with old arrays)** d'= 1.17	t(22) = 2.44, p = 0.023 Cohen's d = 1.04
	3 Objects in arrays (test with new arrays) d'= 1.38	t(22) = 4.46, p = 0.0002 * Cohen's d = 1.82
	4 Scene memory d' = 1.91	t(22) = 2.11, p = 0.046 Cohen's d = 0.90
	5 Objects in scenes (test with old scenes) d'= 1.62	t(22) = 2.97, p = 0.007 * Cohen's d = 1.27
	6 Objects in scenes (test with new scenes) d'= 0.65	t(22) = 10.38, p < 0.0001 * Cohen's d = 4.22
	7 Isolated objects on scenes d' = 0.70	t(22) = 9.58, p < 0.0001 * Cohen's d = 3.90
	8 Isolated, inconsistent objects on scenes d'= 1.10	t(22) = 8.05, p < 0.0001 * Cohen's d = 3.31
	9 Isolated, inconsistent objects on scenes d'= 1.55	t(22) = 5.41, p = 0.0002 * Cohen's d = 2.21

*The difference is statistically significant after being corrected for multiple comparisons using the Holm–Šídák method.

in an array, the items in that array interfered with memory even though they were known to be irrelevant and changed from study to test phases. This occurred even though all stimuli were clearly visible and presented for 3 s, allowing easy fixation on the clearly designated target.

Objects in scenes

An unstructured array of objects provides some, but minimal context. We typically perceive real objects in structured scenes that are congruent or, at least, not incongruent with the object. The next step is therefore to examine memory for objects in scenes.

As a baseline, Experiment 4 first replicated a standard scene memory experiment in which observers encoded 100 whole scenes and then labelled 100 test scenes as old or new. Observers were asked to remember a set of whole indoor scenes that were relatively similar to each other (e.g., there were multiple dining rooms). Recognition memory was quite good for these scenes (Exp. 4 d' = 1.91, s.e.m. 0.17, 18% FA and 82% HIT responses), though not as good as performance for our single objects (Exp. 1 d' = 2.27). This difference was not significantly different when corrected for multiple comparisons (Exp. 1 vs. Exp. 4, t(22) = 2.11, p = 0.046 (uncorrected), Cohen's d = 0.90). The somewhat poorer performance in Exp. 4 is probably due to the choice of scenes. Almost all of the scenes were indoor scenes, and it is likely that memory would have been better if a more diverse set of scenes had been used as they are in most picture recognition tasks. These less memorable scenes were used because they were the type of scenes used as irrelevant backgrounds in subsequent experiments.

In Experiment 5, observers were asked to memorize objects embedded in these scenes (Figure 1c). Observers saw 100 scenes and were asked to

remember only the target object marked by a surrounding red rectangle. As in Experiments 2 and 3, the target objects were unambiguously outlined at encoding and testing. They were told to ignore scenes. At the test phase, the old objects were presented in their original scenes. Results: average d′ = 1.62 (s.e.m. 0. 21) with 27% FA and 81% HIT responses.

One could have plausibly predicted that performance would be the same as it was in isolated objects in Experiment 1. One could even have predicted that performance would have improved since, in principle, the context could have helped to reinstate the memory at the test phase (Tulving & Thomson, 1973). However, when observers were asked to recognize these objects in exactly the same scene at the test, d′ was 1.62. This level of performance was reduced compared to the objects-in-isolation baseline of Exp. 1 (Exp. 1 vs. 5, t(22) = 2.97, p = 0.007, Cohen's d = 1.27). Thus, in seeming contradiction of the encoding specificity effect, memory for a clearly designated target object in a scene is not better than memory for the target alone. In fact, it is somewhat worse than for the scene in its entirety though that effect is not significant (t(22) = 1.278, p = 0.202, corrected for multiple comparison using the Holm–Sidak method). Experiment 5 shows that repeating the scene in study and test phases did not help, when compared to objects presented alone. Is the repetition of a scene in study and test phases at least better than changing the scene between study and test phases? Experiment 6 tests this possibility.

Experiment 6 was identical to Experiment 5 except that, at the test phase, the old target objects are presented on new scene backgrounds. Observers memorized the objects in one scene and were tested with those objects in a different scene (again, with the relevant test object clearly marked).

Here, performance is quite poor (d′ = 0.65, s.e.m. 0.10; 25% FA and 48% HIT responses), dropping dramatically (Exp. 6 d′ = 0.65; Exp. 5 vs. 6, t(22) = 4.23, p = 0.0003, Cohen's d = 1.80), even though observers were told that scene contexts were irrelevant consistent with context shift decrement. The explicitly irrelevant background scenes make memory worse in Experiment 5, compared to no background (Exp. 1). Changing the irrelevant background between study and test phases makes matters even worse. These results are consistent with the hypothesis that encoding of the background is automatic, even if the observer is told to ignore that background (c.f. the flanker and Stroop effects: Eriksen & Hoffman, 1973; Eriksen & Eriksen, 1974; Lleras et al., 2013; Stroop, 1935; MacLeod, 1992). Background objects and their associations or binding with the target enter memory, perhaps crowding or degrading the encoding of target items. If only Experiments 5 and 6 were considered, these results describe a robust context benefit. Memory is better when the context is the same at the test phase as at encoding. However, what is striking here is that both conditions are worse than Experiment 1, where there is no context.

The larger context effect, seen between Experiments 5 and 6 (Cohen's d = 1.80) compared to 2 versus 3 (Cohen's d = 0.65) may reflect the richer set of associations with targets, created by real, plausible scenes compared to unstructured arrays. Contextual cueing studies seem to make a similar point about the power of scene contexts. When naturalistic scenes are used in contextual cueing experiments, the entire scene behaves as the contextual cue (Brockmole et al., 2006). When non-scene arrays of items are used, it is the local elements near the target that are acting as the contextual cue (Jiang et al., 2000; Jiang & Wagner, 2004).

Comparing the stimuli in Figures 1a to 1c, one might argue that memory for objects in scenes is degraded relative to objects in isolation simply because the target objects have lower contrast when embedded in a scene background (1c) than when presented against a blank white background (1a). Perhaps objects in scenes produced poor performance because they were hard to segment from the scene background. To assess this possibility, in Experiments 7, 8, and 9, we perceptually segregated the critical objects from the scenes by erasing the scene inside the red, outline box that had marked the target item in the previous scene experiments (see Figure 1d).

Experiment 7 was identical to Experiment 6 except that the objects were placed in a blank white rectangle, on top of the background scene. In the test phase, the scene behind old objects changed. Performance continued to be quite poor; 35% FA and 61% HIT responses; D′ = 0.70 (s.e.m. 0.11). Consistent with Hollingworth (2006), memory for objects was largely unchanged by this manipulation.
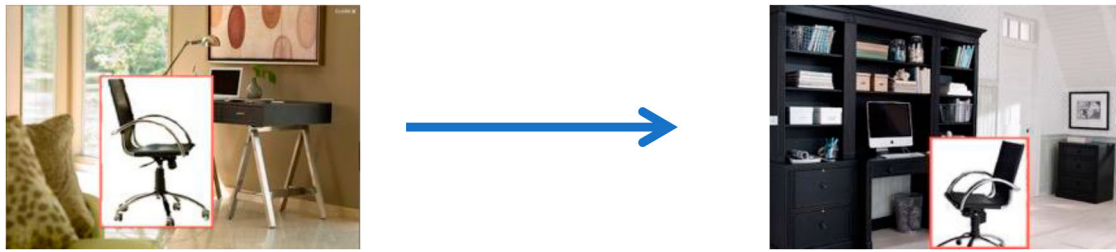
Figure 6. Experiment 7: the test objects are isolated in boxes. The scene changes from study to test phases.

This performance was not significantly better than the equivalent, Experiment 6 (d′ = 0.65), where objects were not perceptually segregated (Exp. 6 vs. Exp. 7 t(22) = 0.38, p = 0.70). This result suggests that placing a "moat" around the critical objects did not eliminate interference from the scene. Some type of meaningful links between scene and object persists.

Experiment 8 provides evidence supporting this conclusion. Perhaps the congruency between scene and target objects made it hard to ignore the scene. Experiment 8 was identical to Experiment 7 except that the target objects in the white box were now semantically inconsistent with the background (e.g., a lawnmower in the kitchen; see Figure 7). In both Experiments 7 and 8, the targets were presented on a white rectangle. The remainder of the scene was congruent with the object in Experiment 7 and incongruent in Experiment 8.

Memory was better when objects were semantically inconsistent with their irrelevant scene context (Exp. 8 34% FA and 74% HIT responses, d′ = 1.10, s.e.m. 0.08; Exp. 8 vs. Exp. 7 t(22) = 2.97, p = 0.007, Cohen's d = 1.21). This is consistent with studies that have found that inconsistent items are remembered better (e.g., it is easier to remember a lawnmower in a kitchen than in a yard: Friedman, 1979; Pezdek et al., 1988; Hollingworth & Henderson, 2000;

Lampinen et al., 2001; Hollingworth & Henderson, 2003). If we imagine that associations with the scene are crowding the memory for the object, the benefit for inconsistent items might be akin to the release from visual crowding when targets and crowding flankers are of different colours (Levi, 2008). Nevertheless, even with the benefit in Exp. 8, memory for the critical objects cannot escape the negative effects of the scene, even though these scenes are irrelevant and inconsistent with the objects. Exp. 8 remains worse than Exp. 1 (see Table 1).

Many theoretical accounts of visual long-term memory (Friedman, 1979; Hollingworth & Henderson, 2002; Pedzek, Whetstone, Reynolds, Askari, & Dougherty, 1989) would predict that the best performance with objects embedded in scenes would be for objects that are semantically inconsistent with a scene but are studied and tested in the same context. The logic of the prediction is the following: at encoding, mismatch signalling for an object that is semantically incongruous to the scene would trigger encoding processes above and beyond typical encoding experiences and establish a new memory trace that distinctly represents the association between the object and the scene. So, in Experiment 9, as in Exp. 8, we tested observers' memory for objects that were incongruent to the irrelevant scene
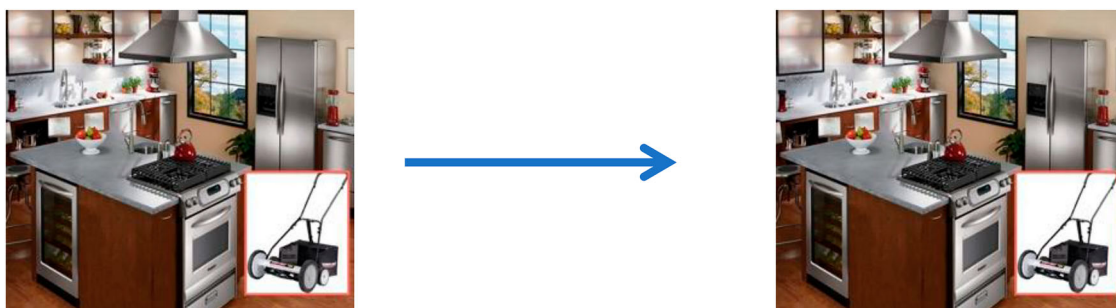

Figure 7. Incongruous target objects on top of different scenes at study and test phases.
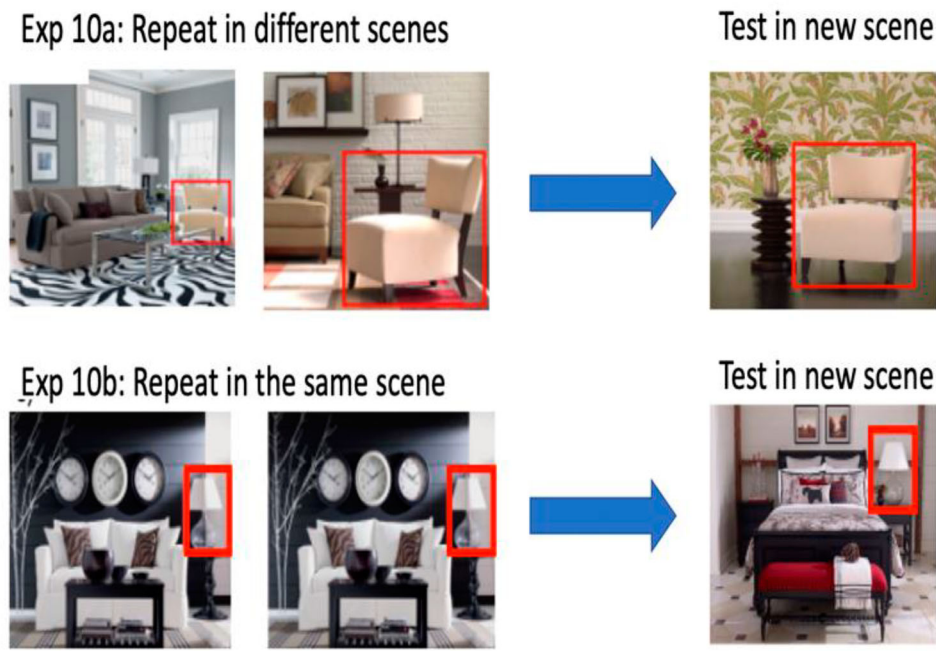
Figure 8. In Experiment 10, observers saw the items twice in the study phase.

context (a lawnmower in a kitchen) but now we did not change the study context from study to the test phase. Semantically incongruent target objects were presented on the same background scenes at study and test phases. Foils were presented on new background scenes at the test phase. As predicted the observers' performance for semantically incongruent objects in repeated scene context (Exp. 9 d′ = 1.55, s.e.m. 0.06; 27% FA and 82% HIT responses) was significantly better than when the scene context changes between study and test phases (Exp. 8 d′ = 1.10; Exp. 8 vs. 9, t(22) = 3.98, p = 0.0006, Cohen's d = 1.90). Performance is similar to Experiment 5, in which test objects were consistent with their backgrounds and present embedded in their background. This suggests that neither consistency nor embedding are important factors. However, performance is still worse than with items in isolation (Exp. 9 vs. Exp. 1 t (22) = 5.41, p = 0.0002, Cohen's d = 2.21).

Decontextualization

The worst performance in this set of experiments comes in Experiments 6 and 7, when encoding occurs with one background scene and testing with another and when the scenes are semantically consistent with the target objects. We argue that tight, automatic associations between target items and sensible backgrounds are crowding or

hiding the mnemonic representation of those targets.

In Experiment 10, we strive to improve memory for the targets objects while continuing to present them on sensible/consistent backgrounds. Perhaps observers simply need more study when objects are encoded in scenes. The experiment is based on the "decontextualization" effect in verbal memory. Decontextualization is the separation of memory of target items from the learning environment context over time (Cox et al., 2014; Winocur et al., 2009). In Experiment 10, observers saw each of the 96 target object twice during encoding, always embedded in a sensible scene. There were two, intermixed, conditions.

In Exp. 10a, each of the two appearances used a different sensible background (akin to seeing your cat in the bedroom and the kitchen). That should produce some decontextualization. In 10b, observers saw each target twice with the same background (akin to repeatedly seeing your toaster in the kitchen; the context remains constant.). As in Experiments 6–8, the objects were presented in another, novel but sensible scene at the test.

Encoding an object in two different scenes (10a: 23% FA and 79% HIT responses; d′= 1.68, s.e.m. 0.12) appears to allow for a more durable representation of that object than encoding twice in the

Exp.11.
Study in isolation   Test in scenes

Exp.12.
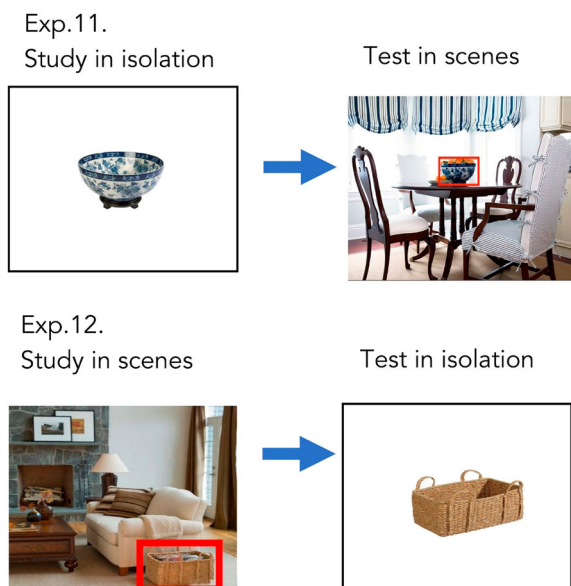Study in scenes   Test in isolation

Figure 9. In Experiment 11, the scene is present only in the test phase. In Experiment 12, the scene is only present in the study phase.

same scene (10b: 25% FA and 60% HIT responses; d'= 1.04, s.e.m. 0.13; Exp. 10a vs. 10b: t(24) = 4.51, p = 0.00014, Cohen's d = 0.90). Again, these findings are also consistent with what we observe in Experiment 9 and the current computational and theoretical view of hippocampus-based memory function, as that of pattern separation by which encoding of new information that overlaps with existing memory representations results in stored representations that focus on the differences between the overlapping episodes (Wiltgen et al., 2010; for a review see Yassa & Stark, 2011).

In Exp. 10b, two exposures to a target item produce somewhat better performance than did one in the otherwise equivalent Exp. 6. The effect is not statistically significant (Exp. 10b: d' = 1.04, Exp. 6 vs. 10b t(35) = 1.96, p = 0.058, Cohen's d = 0.76).

Locus of interference

By far the best performance occurs when objects are studied without scenes. Do scenes cause more trouble in the study or test phases? The final pair of experiments asked if the negative effects of context occur at encoding or at retrieval.

In Exp. 11, one set of objects were studied by observers presented in isolation on a white background and the same objects were presented embedded in scenes at the test phase (retrieval interference condition, Figure 9). As before, objects were clearly marked by a red bounding box. Having the object in isolation in the study phase shows quite good performance (21% FA and 69% HIT responses; d'= 1.36, s.e.m. 0.18) but is still worse than items studied and tested in isolation (t(22) = 11.72, p < 0.0001 comparing to Exp. 1, see Table 1).

In Experiment 12, the scene is present only in the study phase. In Exp. 12, another group memorized objects embedded in scenes and were tested with those objects presented in isolation (encoding interference condition, Figure 9). The results show that having a scene during the study phase is very damaging (36% FA and 60% HIT responses; d' = 0.64, s.e.m. 0.05). Performance is as bad as in Experiment 6, when the scene changed between study and test phases. Negative effects of scene context were much greater in the encoding condition (Exp. 12) than in the retrieval condition (Exp. 11, d' = 1.36; Exp. 11 vs. Exp. 12, t(22) = 3.98, p = 0.0006, Cohen's d = 1.70; see Figure 10). This interference acted both in significantly increasing the false alarm rate (Exp. 11 21% vs. Exp. 12 36%, p = 0.002) and decreasing the hits (Exp. 11 60% vs. Exp. 12 69%; p = 0.03). This differs from the results of Hayes et al. (2007) who reported no difference between interference at retrieval and encoding. They tested a smaller number of objects (40) and scenes (40). Moreover, their scene context was less rich, typically involving one other object (e.g., a target vase on a coffee table as context).

Our primary finding of interference from scenes occurs here as in all other experiments in this series of studies. Encoding isolated objects is better than encoding in scenes (Exp. 11 vs. Exp. 12) but still clearly worse than having isolated objects in both study and test phases.

General discussion

Taken together these 12 experiments support the hypothesis that memory representations of objects cannot be encoded independently of their context even when the context is detrimental to the task. At least, context could not be ignored in these experiments, in spite of our best efforts to make that possible. Though observers were clearly instructed that the context was irrelevant, they consistently showed clear context-dependent effects. Given that the observers were allowed 3 s for encoding of marked objects,
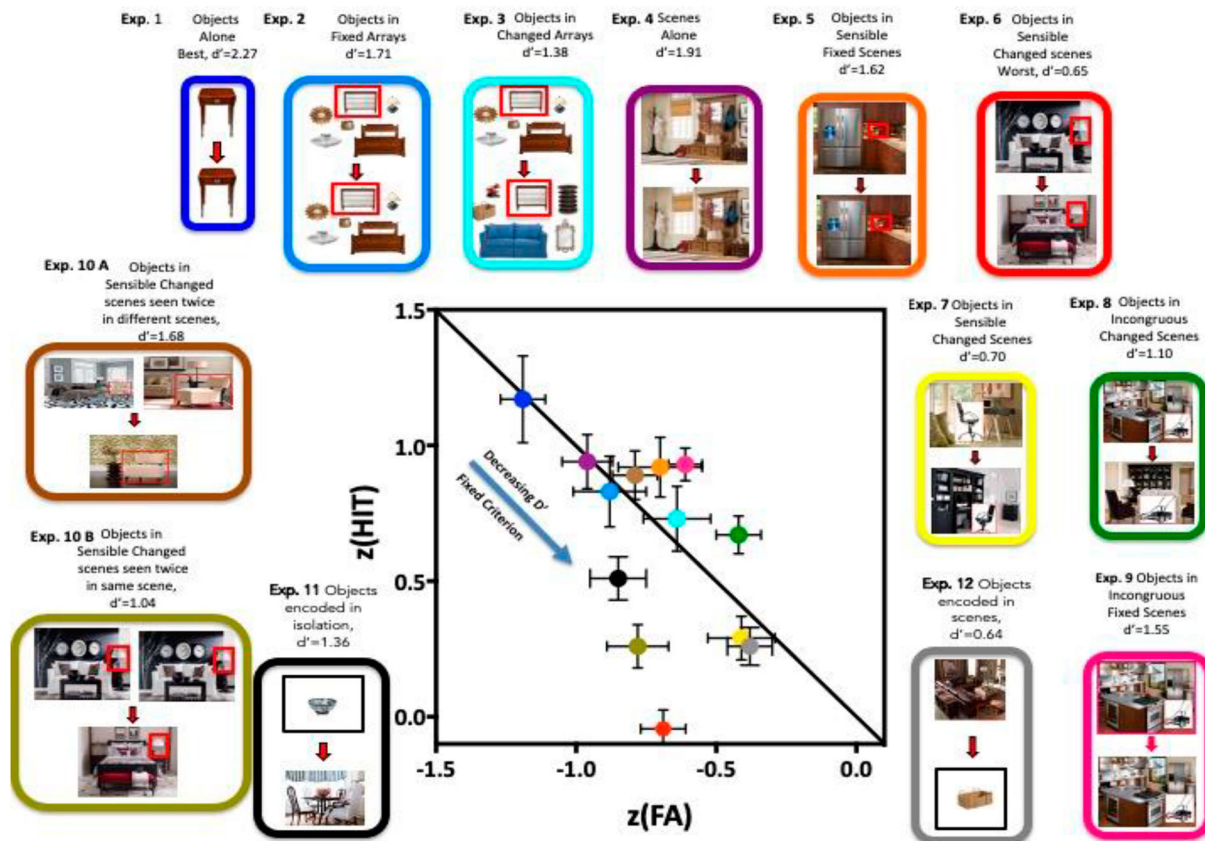
Figure 10. The plot presents memory performance for all 12 experiments by plotting the z-transformed HIT against z-transformed false alarm results on a single receiver operating characteristic (ROC) plot. Each data point represents the average results of one of Experiments 1–12. Neutral criterion (no bias toward either old or new responses) is shown by a diagonal line from upper left to lower right. Better performance on the memory test is indicated by a position closer to the upper left corner of the ROC plot. Average d′ values are also given with each experiment. The error bars are standard errors of the mean.

it is possible that observers explored the rest of the scene when objects were presented embedded in the scene. Thus, it is possible that some of these effects might be less marked with *shorter* study phase exposure. Better memory with less exposure would be an interesting result but beyond the scope of this study.

All of the results of these experiments are summarized in Figure 10. We can see that the baseline condition with no context, produced the highest d′. This is consistent with what Davenport and Potter (2004) report when identification of an object is required. This differs from what has been reported in studies that have examined environmental context effects (Smith & Vela, 2001) and in studies of contextual effect on faces in episodic memory. In those studies, if item–context associations are blocked during study (Memon & Bruce, 1983), there was no observable contextual effect on recognition memory (Smith & Vela, 2001; Memon & Bruce, 1983). There are some

relatively weak environmental context effects in verbal memory recall and only marked if the context actively influences the encoding in memory. Our findings lend support to the idea that objects in scenes are never entirely independent of the surrounding scene context (Hollingworth, 2006) even if they are semantically incongruent to the scene (see Experiment 8). This might be due to the strong contingencies that humans learn over the course of their life between many objects and their contexts. Most of the objects that were part of the memory sets in our experiments do not move on a regular basis and are, thus, strongly bound to typical scene environments in which we experience them. For example, a blender does not move often. It is a kitchen appliance and, thus, a kitchen context is part of its standard representation. It is possible that if the items to be remembered did not have a specific place in which we encounter them on regular basis but can appear anywhere, the context effect might not be so relevant

and strong. Faces might be an example of such a stimulus set, especially if they are not personally relevant faces. Grandma might imply a strong context. Someone else's grandmother probably does not. In experiments with faces, it has been shown that memory for faces is linked to the contexts in which we encounter them only if the memory task instructions imply encoding of the context (e.g., semantic instructions concentrating attention of personality characteristics) (Hayes, Baena, Truong, and Cabeza, 2010; Memon & Bruce, 1983).

Baddeley and Woodhead (1982) offer another way to think about context. In their terms, many of our experiments involve targets that are in an "interactive" relationship with the context. That is, the chair does something in the context of the living room. Those interactive situations may produce stronger context effects (here negative) than more of "independent" contexts. Baddeley (1982) suggest that reports of strong negative verbal context effects on recognition (Tulving & Thomson, 1973) are due to context changing stimulus encoding, where what is encoded is not the word itself but rather a whole scene evoked by its sematic context.

The present results are unusual in showing negative effects of encoding context. Most of the published literature favours beneficial effects of scene backgrounds. It is possible that the difference may lie in the size of the memory load. In our studies, observers are trying to hold 100 encoded objects in some form of "activated long term memory" (Cowan, 1988) for the subsequent test. In studies that show a benefit of scene background, observers are typically holding just one or a few targets in memory (Hollingworth, 2006). With 100 objects and 100 scenes jostling each other in memory, we may be seeing the interference more clearly. Melcher, in his 2001 study, also reports interference with memory for 12 new objects presented on old background scenes irrelevant to the task being poorer than for completely new backgrounds; an effect seen only for images of objects and not object names. More generally, these results point to a fundamental property of episodic memory. The components of an episode are hard to disentangle from the entire episode. That is, when objects are presented in a context, especially as part of a real scene, the encoding trace is tightly bound to the context and to that specific episodic instance. Only when we dissociate an object's representation

in memory from the context in which it was encoded by having observers encode the object in a different context (Exp. 10a) there is some release from mnemonic crowding (e.g., abstraction from source memory or decontextualization) and the memory trace of the object is less strongly bound to a specific episode, though even in that case, the presence of scenes reduces performance.

In conclusion, context appears to be inescapable in the encoding and retrieval of episodic memory for objects. A scene context has its effects even when it is task irrelevant or is not consistent with the target objects. A scene context has an effect on an object even when that object is clearly not part of the scene at all. This incidental tight binding might be beneficial, facilitating object identification or retrieval from memory when the mnemonic load is not high in episodic memory and when context is reinstated at the test phase. However, when there is a lot to remember, context interferes.

The methods described here might be a different way to look at those fundamental effects of context in memory that are able to turn a stop sign in the world into a yield sign in the mind's eye of an observer or a allow a gun or knife to move from the hand of one actor in the world to another by the time the event is recalled (Hupbach et al., 2008; Loftus, 1992; Loftus et al., 1983).

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Disclosure statement

Data availability statement

The data that support the findings of this study are available from the corresponding author, KKE, upon reasonable request.

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