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Recognition-induced forgetting is not due to category-based set size

Ashleigh M. Maxcey[1]

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Abstract What are the consequences of accessing a visual long-term memory representation? Previous work has shown that accessing a long-term memory representation via retrieval improves memory for the targeted item and hurts memory for related items, a phenomenon called retrieval-induced forgetting. Recently we found a similar forgetting phenomenon with recognition of visual objects. Recognition-induced forgetting occurs when practice recognizing an object during a two-alternative forced-choice task, from a group of objects learned at the same time, leads to worse memory for objects from that group that were not practiced. An alternative explanation of this effect is that category-based set size is inducing forgetting, not recognition practice as claimed by some researchers. This alternative explanation is possible because during recognition practice subjects make old-new judgments in a two-alternative forced-choice task, and are thus exposed to more objects from practiced categories, potentially inducing forgetting due to set-size. Herein I pitted the category-based set size hypothesis against the recognition-induced forgetting hypothesis. To this end, I parametrically manipulated the amount of practice objects received in the recognition-induced forgetting paradigm. If forgetting is due to category-based set size, then the magnitude of forgetting of related objects will increase as the number of practice trials increases. If forgetting is recognition induced, the set size of exemplars from any given category should not be predictive of memory for practiced objects. Consistent with this latter hypothesis, additional practice systematically improved memory for practiced objects, but did not systematically affect forgetting of related objects. These results firmly establish that recognition practice induces forgetting of related memories. Future directions and important real-world applications of using recognition to access our visual memories of previously encountered objects are discussed.

Keywords Memory: Long-term memory · Visual perception · Retrieval-induced forgetting · Recognition-induced forgetting · Visual long-term memory · Recognition memory

Introduction

Every time we use a piece of information stored in memory, are we hurting the information that we are not using? Experiments examining the retrieval of verbal materials have shown that remembering a target item can result in the misremembering of related items (Anderson et al., 1994; Murayama, Miyatsu, Buchli, & Storm, 2014). Recently Maxcey and Woodman (2014) demonstrated seemingly similar effects, but with the critical distinction of using recognition practice of visual objects rather than retrieval practice of verbal stimuli (see also Maxcey & Bostic, 2015). We showed that remembering a visual object was accompanied by the forgetting of related objects learned at the same time, an effect termed *recognition-induced forgetting*. We use the term recognition-induced forgetting to describe the stimulus characteristics of the paradigm, distinguishing our paradigm from retrieval-induced forgetting while remaining mechanistically neutral. In the present study I describe the theoretical importance of recognition-induced forgetting and rule out an alternative explanation of forgetting, that it is due to category-based set size.

In recognition-induced forgetting, participants are sequentially presented with objects to remember during a study phase (see Fig. 1). After seeing them all, participants practice

✉ Ashleigh M. Maxcey
amaxcey@tnstate.edu

1 Department of Psychology, Tennessee State University, 3500 John Merritt Blvd., Nashville, TN 37209-1561, USA

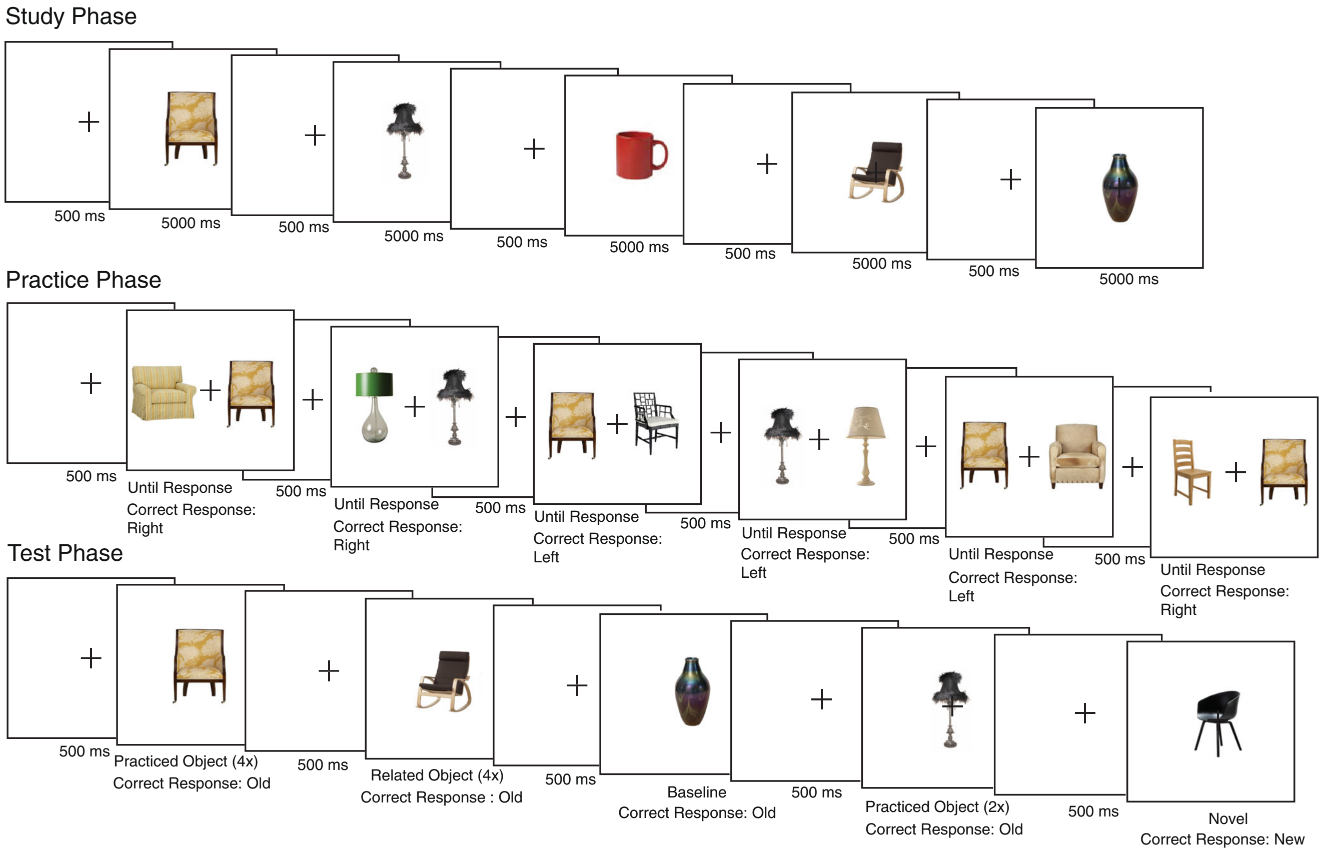

Fig. 1 Example of the stimuli and procedure. The study phase consisted of 78 objects presented sequentially for 5 s interleaved by a 500-ms fixation cross. Participants were instructed to study the visual details of each image for a later memory test. During the practice phase participants were shown half of the objects from half of the categories from the study phase. These objects were paired with a novel exemplar from the same category. Participants responded by button press to indicate which object (the object on the left or on the right) was the object they studied in the previous phase. Half of these objects were practiced on two trials in the practice phase (e.g., the silver lamp with a black fuzzy shade) and the rest were practiced on four trials (e.g., the yellow chair with white flowers). During the test phase participants responded whether an object was old (they had seen it earlier in the experiment) or new (they had never previously seen the object)

recognizing some of these objects in a two-alternative forced-choice task. The objects participants practice go by the straightforward name of *practiced objects*[1] (e.g., the yellow chair with white flowers in Fig. 1). The design includes other objects from the practiced categories that are shown during the study phase but are not practiced during the recognition-practice phase (e.g., the remaining chairs that were not practiced). These are known as *related objects* (e.g., the black upholstered rocking chair in Fig. 1) because of their status as belonging to a practiced category (e.g., chairs). Finally, there are *baseline objects*, so named because they belonged to categories from which none of the objects are practiced (e.g., none of the vases in Fig. 1 are practiced).

In the test phase, participants are presented with one object at a time.[2] Half of the test objects were old (practiced objects, related objects, and baseline objects from earlier in the experiment) and half were new (novel objects never before seen during the experiment). Practice lures were not included in the final memory test because pilot studies showed participants were confused as to whether those objects warranted a "yes" or "no" response when directed to indicate if they had seen an object previously in the experiment. Participants report whether they have ever seen that exact object previously

[1] Note that for the sake of accessibility to the reader, we (Maxcey & Bostic, 2015) revised the nomenclature used in our previous recognition-induced forgetting paradigm (Maxcey & Woodman, 2014) by using the term "*practiced objects*" to refer to objects that were previously denoted "Rp+ items", "related objects" to refer to objects previously denoted "Rp- items," and "*baseline* objects" to refer to objects that were previously called "Nrp items."

[2] The final test phase involved a yes/no object recognition test whereas the middle practice phase involved a two-alternative forced-choice recognition task. The final yes/no recognition test allowed for clean correct rejection rates in the present experiment to distinguish between the two hypotheses tested herein. A large body of evidence suggests that recognition involves two different processes (Mandler, 2008) and the relative dependence on these processes may vary by the type of recognition test (Holdstock et al., 2002). As such, future work should examine the presence of recognition-induced forgetting when the tasks in both the practice and test phases are equated.

in the experiment with a button press response (i.e., old or new recognition judgment).

Using the recognition-induced forgetting paradigm, Maxcey and Woodman (2014) showed that recognition practice improved memory for practiced objects relative to memory for baseline objects. More importantly, recognition practice also decreased memory for related objects relative to memory for baseline objects (see also Maxcey & Bostic, 2015). Baseline objects and related objects were both only presented one time, during the study phase. Thus, the only difference between related and baseline objects is that related objects belong to categories of practiced objects. It is clearly that relationship, belonging to a category that has some practiced objects, that results in poorer memory for related objects relative to baseline objects.

Evidence of recognition-induced forgetting in the Maxcey and Woodman (2014) paradigm is theoretically important for a number of reasons. First, it has been well established that memory for pictures is better than memory for words (Durso & O'Sullivan, 1983; Gehring, Toglia, & Kimble, 1976; Hockley, 2008; Juola, Taylor, & Young, 1974; Madigan, 1974; Nelson, Reed, & McEvoy, 1977; Nelson, Reed, & Walling, 1976; Paivio & Csapo, 1973; Paivio, Rogers, & Smythe, 1968; Snodgrass & Burns, 1978; Snodgrass, Volvovitz, & Walfish, 1972; Snodgrass, Wasser, Finkelstein, & Goldberg, 1974), despite considerably more of the existing research on long-term memory having been conducted using verbal stimuli (Palmer, 1999). This led Maxcey and Woodman to predict that memory for pictoral stimuli in visual long-term memory would be immune to forgetting effects shown with words (e.g., retrieval-induced forgetting) and thus unimpaired following recognition practice (see also Ciranni & Shimamura, 1999; Fan & Turk-Browne, 2013; Shaw, Bjork, & Handal, 1995; Waldhauser, Johansson, & Hanslmayr, 2012). Contrary to their prediction, practice recognizing pictoral stimuli led to the forgetting of related stimuli. Second, a handful of previous studies on retrieval-induced forgetting have used recognition tasks during the final test phase (e.g., Gómez-Ariza, Lechuga, Pelegrina, & Bajo, 2005; Hicks & Starns, 2004). However, all these studies used retrieval practice during the middle practice phase.[3] This means that the forgetting in those studies was induced by retrieval, hence that effect is called *retrieval*-induced forgetting. Maxcey and Woodman (2014) used *recognition* practice, hence that effect is called *recognition*-induced forgetting. Third, accessing information in long-term memory has recently been shown to have beneficial effects on memory under some circumstances. For example, recent work by Little and colleagues examining multiple choice tests (Little & Bjork, 2015; Little, Bjork, Bjork, & Angello, 2012) has suggested that forced-choice memory paradigms need not lead to forgetting of competitors. Given that retrieval can benefit memory under some circumstances, it is not intuitively obvious that forgetting of related visual objects would have occurred in the Maxcey and Woodman paradigm. Fourth, studies examining socially shared retrieval-induced forgetting (Coman & Hirst, 2012; Coman, Manier, & Hirst, 2009; Cuc, Koppel, & Hirst, 2007; Koppel, Wohl, Meksin, & Hirst, 2014) have shown that passive listeners exhibit forgetting induced by others' selective retrieval. Socially shared retrieval-induced forgetting suggests that overt forms of retrieval might not be necessary for induced forgetting and perhaps generalizes to other modalities.

Given the theoretical importance of observing the recognition-induced forgetting outlined above, it is critical to clearly establish its existence. Although Maxcey and Woodman (2014) purported to observe recognition-induced forgetting, their findings may be accounted for by a simple alternative explanation. This alternative explanation states that the forgetting of related objects occurs in the Maxcey and Woodman (2014) paradigm due to category-based set size.[4] The category-based set size account of recognition-induced forgetting is akin to the well-known list-length effect in recognition memory. The list-length effect states that it is more difficult to remember items from a longer list relative to items from a shorter list (Strong, 1912). This is a plausible explanation for the Maxcey and Woodman results because during the recognition practice phase, related objects belong to a larger set of objects than baseline objects. This is because during each trial of recognition practice, a lure object from the same category is paired with the practiced object and participants are instructed to report which object is from the study phase. The presentation of practice lures increases the total number of objects to which the participant is exposed from the practiced categories relative to the unpracticed categories. For example, participants study six vases and six chairs and then practice recognizing three of the chairs. During recognition practice, each of the three practiced chairs is paired with a novel chair and asked which chair they had previously seen in the experiment. Further, each object is practiced twice, on two different trials. This means that at test, participants have seen twelve chairs (six from the study phase and six lures from the practice phase) and only six vases. This larger (in fact, doubled) set size for objects from practiced categories may drive forgetting of related objects relative to baseline objects due to more interference for categories of practiced objects (e.g., twelve

[3] Notably, an experiment by Verde (Verde, 2004, Experiment 2) which gave rise to retrieval-induced forgetting, did include an associative recognition practice task using word pairs. However, in that experiment due to the manipulation being tested, there was an order confound at test.

[4] This hypothesis already has some support in the literature. Specifically, Verde (Verde, 2013, Experiment 6) demonstrated that increasing the number of novel exemplars for practiced categories, thereby increasing the set size of competitors in memory for practiced items, reliably decreased memory for related items accompanied by a marginal decrease in memory for practiced items.

total chairs) relative to categories of non-practiced objects (e.g., six total vases). To convincingly argue that recognition practice is inducing forgetting, such that the Maxcey and Woodman (2014) results truly exhibit *recognition-induced* forgetting, it is critical to demonstrate that category-based set size is not driving the effect.

In the present study, I used a parametric manipulation of the amount of practice each object received in the recognition-induced forgetting paradigm (Maxcey & Woodman, 2014) to distinguish between two competing hypotheses. On one hand, the *recognition-induced forgetting hypothesis* states that forgetting in this paradigm is truly recognition-induced in that it is driven by the recognition practice that occurs during the second phase of the paradigm. Alternatively, the *category-based set size hypothesis* suggests that forgetting is not recognition-induced but rather due to category-based set size, as described above. To distinguish between these alternatives, participants practiced recognizing objects two or four times in Experiment 1 and two, four, or six times in Experiment 2. Increasing the number of practice trials an object received also increased the set size for the practiced object category because each practice trial included a novel lure.

The parametric manipulation allowed for three distinct measures to distinguish between the two competing hypotheses. First, if category-based set size is driving forgetting in this paradigm, causing it to be more difficult to recognize related objects from practiced categories relative to baseline objects from non-practiced categories, then additional practice trials (and thereby increased set sizes due to increased practice lures) should yield increasingly worse memory for related objects. Specifically, memory for related objects from categories that were practiced four times should be worse than memory for related objects from categories that were practiced only twice.

Second, at test, participants completed a recognition test. Half of the objects were new objects drawn from the same categories as the objects during the study phase (e.g., new chairs, new vases). Recall that the category-based set size account purports that it is harder to accurately remember objects from practiced categories due to increased set size. If this is true, results should show fewer correct rejections of novel test lures from categories that are practiced four times relative to categories that are practiced twice. This decrease in correct rejections for novel test lures from categories with more practice lures would indicate that participants are worse at differentiating between familiar and unfamiliar objects because they come from a larger set size.

A third measure that will help distinguish between the two competing hypotheses is between practiced and non-practiced categories. Categories that are practiced have a larger set size than non-practiced categories. If the category-based set size account explains recognition-induced forgetting, novel test lures that belong to practiced categories should have fewer correct rejections than categories that are not practiced due to the increased set size created during practice.

Experiment 1

Method

Participants

Twenty-four individuals from Manchester University, aged 18–30 years, who passed the Ishira color blindness test, and reported normal or corrected-to-normal vision, participated in exchange for course credit or pay. Informed consent was obtained prior to procedures approved by the Manchester University Institutional Review Board.

Stimuli

Stimuli were presented on a flat-screen 16-in CRT monitor using E-prime 2.0 software (Schneider, Eschmann, & Zuccolotto, 2012). A viewing distance of 80 cm was controlled by a forehead rest. Stimuli were drawn from a set of 360 pictures of real-world objects (public domain images downloaded from Google Images http://images.google.com), subdivided into 12 categories with 30 exemplars in each category. Stimuli were viewed on a white background, with each subtending 9.44° × 7.13° degrees of visual angle.

Procedure

An example of the stimuli and procedure is shown in Fig. 1. Each session began with a study phase. During the study phase, participants were shown one object at a time for 5 s, interleaved by a 500-ms center fixation cross, until 78 objects had been randomly presented. Objects were randomly selected and belonged to 12 categories (e.g., mugs, lamps, chairs, vases) with six exemplars in each category (e.g., six different mugs, six different lamps, six different chairs, six different vases). Participants were instructed to study the visual details of these objects for a later memory test. They were told that the later test would require memory for an object as detailed as "red bike with banana seat;" therefore, simply remembering the category "bike" would not help at test. Prior evidence (Maxcey & Woodman, 2014) supports that the effect is visual in nature and does not rely on covert verbal labeling of stimuli or the retrieval of verbal information. To minimize the influence of primacy and recency effects (Murdock, 1962), three filler objects from two additional categories were included in the beginning and end of the study phase but were not included in the analysis. Thus, six of the 78 objects were excluded from analysis due to their status as filler objects.

The purpose of the second phase, the recognition-practice phase, was to provide participants with practice remembering a subset of objects from the study phase. On each trial of recognition practice, participants were shown two objects, one to the left and one to the right of fixation. One of the objects was an object they were shown during the study phase and was thus a *practiced object* (e.g., the yellow chair with white flowers). The other object was a novel *practice lure* from the same category (e.g., the novel white and yellow striped chair shown in Fig. 1). Participants were instructed to determine which of the objects they had seen before (i.e., which was old) and respond with a two-alternative forced-choice button press. They pressed the left key on the response box with their right index finger if the old object was on the left and the right key on the response box with their middle finger if the old object was on the right. The trials were response terminated and followed by a 500-ms center fixation cross before the next trial.

During the preceding study phase, participants had been shown six different objects from 12 categories (e.g., six different mugs, six different chairs, six different lamps, six different vases). Then, in this recognition-practice phase, participants practiced recognizing half of the objects from half of the categories from the study phase (i.e., three objects from six categories, drawn from the larger set of study phase objects consisting of six objects from 12 categories). To parametrically manipulate the amount of practice the objects received, half of the practiced categories (three out of six) were practiced twice on two trials (three objects from three categories practiced twice, $3 \times 3 \times 2 = 18$ trials), and the remaining half were practiced four times on four trials (three objects from three categories practiced four times, $3 \times 3 \times 4 = 36$ trials). The practice phase consisted of a total of 54 randomly presented trials. Before and after recognition practice, participants completed a 5-min distractor task involving searching for Waldo in *Where's Waldo* books.

During the third and final phase, the test phase, participants were shown one object at a time and asked to report whether they had ever seen the exact image previously in the experiment, at any point, and respond with a button press. They pressed the left key on the response box with their right index finger to report that the object was old and the right key on the response box with their right middle finger to report that the object was new, from this point forward known as the old-versus-new judgment. Instructions to the participants stressed accuracy of responses, not speed.[5]

The test phase images fell into four categories. In three of the categories the objects were previously seen and a correct response was "old": (1) *practiced objects* were shown both during the study phase and practiced in the recognition-practice phase, (2) *related objects* were shown during the study phase and then were *not* practiced in the recognition-practice phase but their category was practiced (e.g., chairs were practiced but not that specific chair), (3) *baseline objects* were shown during the study phase and then were *not* practiced in the recognition-practice phase and their category was *not* practiced (e.g., a vase from the study phase and vases were not practiced). As a result of the parametric manipulation, half of the practiced objects were practiced twice and the remaining practiced objects were practiced four times. Half of the related objects were drawn from categories that were practiced twice and the remaining related objects were drawn from categories that were practiced four times. The fourth category consisted of *test lures*, which were new objects to which a correct response would be "new." Test lures were drawn from all of the same 12 categories as the objects during the study phase, such that half of the test lures belonged to the six practiced categories and six belonged to non-practiced categories. However, test lures were novel objects belonging to these categories (e.g., new lamps, new mugs, new chairs, new vases). Practice lures that were selected against during the recognition-practice phase (e.g., the white and yellow striped chair) were never included in the test phase. However, instructions given to the participants before they began the test phase clearly stated that if they had *ever* seen an object before, at any point in the experiment, they should answer "old."

At test participants were presented with 72 new objects (i.e., test lures) and 72 old objects so that "old" and "new" responses were equally probable. The 144 test trials were composed of (a) three practiced objects and three related objects from each of the 6 practiced categories (36 trials), (b) six baseline objects from each of the six non-practiced categories (36 trials), and (c) six novel test lures from each of the 12 categories (72 trials). All objects were randomly presented during test, regardless of their membership in any of these types of trials.

Data analysis

The primary dependent variable for the recognition data was percent correct (i.e., hits for practiced, baseline and related objects), and correct rejections for test lures. I found the same pattern of results when I computed *A*' (Snodgrass, Levy-Berger, & Haydon, 1985), so for efficiency of presentation only percent correct is reported. This was done because the *A*' measure of sensitivity combines hits and false alarms from novel and previously seen test items. Within-subjects analysis of variance (ANOVA) was used for the omnibus test, and pre-planned, pairwise analyses were two-tailed repeated measures t-tests. All t-tests are accompanied by measures of Cohen's *d* effect size. To provide a way of quantifying the support for the null hypothesis, I calculated the scaled JZS

[5] Verde and Perfect (Verde & Perfect, 2011) found retrieval-induced forgetting occurred on unspeeded recognition tasks (purported to be driven by both recollection and familiarity) but not on speed-stressed recognition tests (thought to be primarily on based familiarity). These findings suggest that evidence of recognition-induced forgetting may differ under circumstances of speeded responses (a currently untested possibility within this paradigm), which could potentially help establish whether recognition is an independent probe of memory (Storm & Levy, 2012; Verde & Perfect, 2011).

Bayes Factor (as specified in Rouder, Speckman, Sun, Morey, & Iverson, 2009). In analyses of correct rejections of novel test items, the primary dependent variable is accuracy (% correct).

Results

The mean accuracy of subjects' old-versus-new judgments across the types of test objects for which the correct answer is "old" is shown in Fig. 2. These means show that increased practice reliably improved memory for practiced objects, but did not reliably affect forgetting of related objects. These findings resulted in a significant main effect of trial type in the ANOVA, $F(4,92) = 37.67.73$, $p < .001$, that is parsed in the following analyses.

Canonical remembering and forgetting effects

First, I examined the data to confirm that recognition practice improved memory for practiced objects and impaired memory for related objects relative to baseline. For this analysis, I used practiced and related objects from categories that were practiced twice because they mimic the amount of practice in our previous paradigm (Maxcey & Woodman, 2014). Indeed, recognition practice reliably improved memory for practiced objects (83 %) relative to baseline (65 %), $t(23) = 5.81$, $p < .001$, $d = 1.25$, and impaired memory for related objects (48 %) relative to the same baseline (65 %), $t(23) = 3.91$, $p < .001$, $d = 0.82$.

Consistent with the effect of practice reported above, participants performed very well during the practice phase. During the middle practice phase, participants correctly selected the object from the study phase during the two-alternative forced-choice task on 90 % of trials. This 90 % accuracy was comprised of 88 % for objects that were practiced on two trials and 92 % accuracy for objects that were practiced on four trials, a 3.7 % difference that was statistically significant $t(23) = 2.12$, $p = .045$, $d = 0.32$. Having replicated the two basic effects in this paradigm, I next turn to the results of the parametric manipulation.

Parametric manipulation

Next, I examined whether additional practice increased memory for practiced objects and, as predicated by the category-based set size account, increased forgetting of related objects. Recognition practice improved later recognition of practiced objects when those objects were practiced four times (92 %) relative to when those objects were practiced twice (83 %), $t(23) = 2.84$, $p = .009$, $d = 0.65$. However, recognition practice did not hurt later recognition of related objects when those objects belonged to categories of practiced objects that were practiced twice (48 %) relative to related objects drawn from categories of practiced objects that were practiced four times (48 %), $t(23) = 0.09$, $p = .933$, $d = 0.02$, and a scaled JZS Bayes Factor of 4.64, indicating that the null hypothesis is over four times more likely than the hypothesis that forgetting differed as a function of practice. The absence of a parametric effect on forgetting does not appear to be a floor effect. When I analyzed just the top performing half of subjects (by ranking them in order of their average hit rate for baseline objects and then analyzing the top 50 %), their mean recognition for the related objects was relatively high (62 % for 2× practice and 56 % for 4× practice), but showed no evidence of forgetting that varied systematically with practice, $t(11) = 0.97$, $p = .352$, $d = 0.28$, and a scaled JZS Bayes Factor of 2.35.

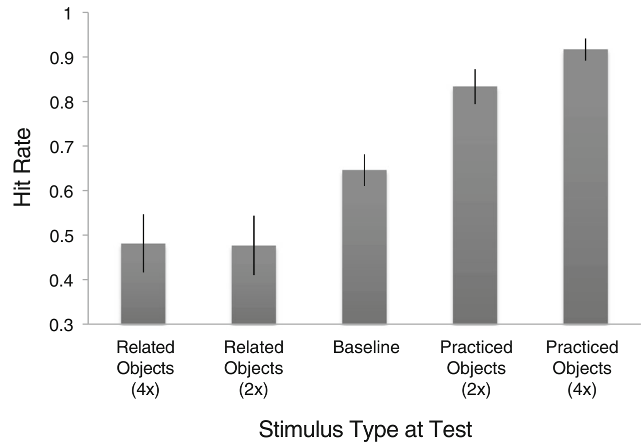

Fig. 2 Hit rates of the responses to the old memory test objects in the test phase of Experiment 1. *Practiced objects* were recognized during the practice phase (e.g., the yellow chair with white flowers). Practiced objects (2×) refers to objects that were practiced twice (e.g., lamp), whereas Practiced objects (4×) refers to objects that were practiced four times (e.g., chair). *Related objects* are the objects that belong to practiced categories (e.g., chair) but were not themselves practiced (e.g., this particular black rocking chair was not practiced). Related objects (2×) refers to related objects that belong to categories that were practiced twice (e.g., lamp), and Related objects (4×) refers to related objects that belong to categories that were practiced four times (e.g., chair). *Baseline* means this entire category of objects (e.g., vases) was not practiced. The error bars in this and subsequent figures show the 95 % within-subjects confidence intervals as described by (Cousineau, 2005) with Morey's correction applied (Morey, 2008)

Correct rejections of novel test lures

The lack of a significant effect on forgetting as a function of increased practice (and thereby increased set size due to additional practice lures) indicates that the category-based set size account is incorrect. Recall that the category-based set size account posits that worse memory for related objects relative to baseline objects found by Maxcey and Woodman (2014) is due to increased set size of related objects relative to baseline objects. If this were the case, then the difficulty presented by increased set size would not only emerge as worse memory for objects drawn from categories with larger set sizes, it would also emerge as impaired ability to correctly reject novel objects from those same categories. Therefore to further examine this alternative explanation, I examined the percent of correct rejections of novel test lures to objects that belonged to categories that were practiced two versus four times. These means show that increased practice, and thereby increased set size (because each practice trial required a novel lure), did not reliably affect correct rejections of test lures. Participants correctly rejected novel test lures that belonged to a category that was practiced twice (94 %) at a similar rate as those that belonged to a category that was practiced four times (92 %), $t(23) = 0.71$, $p = .484$, $d = 0.21$, and a scaled JZS Bayes Factor of 3.71. These findings indicate that despite belonging to categories with a varying number of competitors, participants' ability to correctly reject novel objects was not reliably affected. In addition, novel test lures from all non-practiced categories were correctly rejected at reliably worse rates (83 %) than novel test lures from all practiced categories (93 %), $t(23) = 7.50$, $p < .001$, $d = 1.46$, an inverse pattern than predicted by the category-based set size effect account because non-practiced categories had smaller set sizes.

Discussion

These results support that recognition-induced forgetting is due to recognition practice rather than category-based set size. First, additional practice trials increased the set size of objects from those categories (because each practice trial required a novel practice lure) but did not result in increased forgetting of related objects. Second, the correct rejection rates to novel test lures did not significantly differ between practiced categories of different set sizes. If category-based set size accounts for forgetting, correct rejections of novel test lures from categories of objects that were practiced more, and hence had larger set sizes, should have been reliably worse. Third, participants were better at correctly rejecting novel test lures from practiced, rather than non-practiced, categories despite that non-practiced categories were composed of smaller set sizes. If category-based set size were driving this effect, increasing the number of competitors in practiced categories should have impaired performance, but it did not.

As reported above, memory for practiced objects in Experiment 1 did significantly increase with practice (from 83 % 2× practice to 92 % 4× practice). This affords the possibility that additional practice would further increase memory for practiced objects and would also increase the number of competitors in memory, potentially showing an effect on forgetting related objects as a function of set size that I did not find in Experiment 1. To rule out the possibility that there was an insufficient amount of practice in Experiment 1 to see a related degree of forgetting of related objects, in Experiment 2, I had subjects practice objects two, four, or six times.

Experiment 2

Method

Participants

Thirty-four naïve observers participated in Experiment 2 in exchange for course credit or payment. The screening criteria were identical to Experiment 1.

Stimuli and procedures

All methods were identical to Experiment 1, except as follows. Practiced objects were practiced either two, four, or six times. The practice phase was therefore longer in Experiment 2 than Experiment 1, with two categories practiced twice (three objects from two categories practiced twice, $3 \times 2 \times 2 = 12$ trials), two categories practiced four times (three objects from two categories practiced four times, $3 \times 2 \times 4 = 24$ trials) and two categories practiced six times (three objects from two categories practiced six times, three × 2 × 6 = 36 trials), totaling 72 practice trials.

Results

The mean accuracy of subjects' old-versus-new judgments across the types of test objects is shown in Fig. 3. Replicating Experiment 1, the means were again inconsistent with the category-based set size hypothesis and consistent with the recognition-induced forgetting hypothesis because increased practice reliably improved memory for practiced objects but did not affect forgetting of related objects. These findings resulted in a significant main effect of trial type in the ANOVA, $F(6,198) = 59.87$, $p < .001$, that is parsed in the analyses below.

Canonical remembering and forgetting effects

Recognition practice reliably improved memory for practiced objects (86 %) relative to baseline (65 %), $t(33) = 6.36$, $p < .001$, $d = 1.28$, and impaired memory for related objects (42 %) relative to the same baseline (65 %), $t(33) = 5.64$, $p < .001$, $d = 1.04$.

Consistent with the effect of practice reported above, participants performed very well during the practice phase. During the middle practice phase, participants correctly selected the object from the study phase during the two-alternative forced-choice task on 95 % of trials. This 95 % accuracy

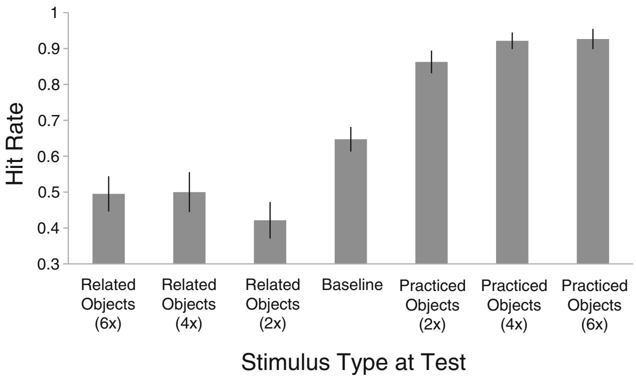

Fig. 3 Hit rates of the responses to the old memory test objects in the test phase of Experiment 2

was comprised of 94 % for objects that were practiced on two trials, 96 % accuracy for objects that were practiced on four trials, and 94 % accuracy for objects that were practiced on six trials, a difference that was not statistically significant (ANOVA, $F(2,76) = 1.89$, $p = .158$). Having replicated the two basic effects in this paradigm, I next turn to the results of the parametric manipulation.

Parametric manipulation

Recognition practice improved later recognition of practiced objects when those objects were practiced four times (92 %) relative to when those objects were practiced twice (86 %), $t(33) = 2.17$, $p = .038$, $d = 0.42$. However, recognition practice did not further improve memory for practiced objects when those objects were practiced six times (93 %) relative to four times (92 %), $t(33) = 0.24$, $p = 0.812$, $d = 0.04$, and a scaled JZS Bayes Factor of 5.30. This indicates that the benefit of additional practice on practiced objects had reached asymptote by four practice trials.

In contrast to the systematic benefit of recognition practice on practiced objects, practice did not hurt later recognition of related objects drawn from categories that were practiced twice (42 %) relative to related objects drawn from categories that were practiced four times (50 %), $t(33) = 1.80$, $p = .081$, d = 0.28, and a scaled JZS Bayes Factor of 1.28. In fact, the results show a trend in the opposite direction. That is, if anything increased practice resulted in a modest improvement in memory for the related objects. This is contrary to the category-based set size hypothesis, which posits that increased practice trials (and thereby increased set size because each practice trial includes a lure from the same category) should demonstrate greater forgetting. Recognition practice did not hurt later recognition of related objects when those objects belonged to categories of objects that were practiced six times (50 %) relative to related objects drawn from categories of objects that were practiced four times (50 %), $t(33) = 0.11$, $p = .911$, $d = 0.02$, and a scaled JZS Bayes Factor of 5.41. Finally, recognition practice did not impair later recognition of related objects when those objects belonged to categories of objects that were practiced six times (50 %) relative to related objects drawn from categories of objects that were practiced twice (42 %), $t(33) = 1.63$, $p = .113$, $d = 0.29$, and a scaled JZS Bayes Factor of 1.65. The absence of a parametric effect on forgetting does not appear to be a floor effect. When I analyzed just the top performing half of subjects (divided by memory for baseline objects), their mean recognition for the related objects was relatively high (56 % for 2× practice, 67 % for 4× practice, and 63 % for 6× practice), but showed no evidence of forgetting that worsened systematically with practice as predicted by the category-based set size effect hypothesis. In fact, recognition memory for objects from categories that were practiced four times (67 %) was reliably better than recognition memory for objects from categories that were practiced only twice (56 %, $t(16) = 1.65$, $p = .119$, $d = 0.49$). This difference shows an inverse pattern of results relative to that predicted by the category-based set size hypothesis, which states that an increase in the set size of objects should worsen recognition memory for related objects.

Correct rejections of novel test lures

Next, I examined the percent of correct rejections of novel test lures to objects that belonged to practiced categories. These findings did not result in a significant main effect of trial type in the ANOVA, $F(2,66) = 1.33$, $p = .272$. These means show that increased practice, and thereby increased set size (because additional trials of practice require additional novel practice lures), did not reliably affect correct rejections of test lures. Participants correctly rejected novel test lures that belonged to a category that was practiced twice (92 %) at a similar rate as those that belonged to a category that was practiced four times (95 %) and those that belonged to a category that was practiced six times (93 %). These findings indicate that despite increases in set size, participants' ability to correctly reject novel objects was not reliably affected.

In addition, novel test lures from all non-practiced categories were correctly rejected at reliably worse rates (82 %) than novel test lures from all practiced categories (93 %), $t(33) = 8.66$, $p < .001$, $d = 1.10$, an inverse pattern than predicted by the category-based set size effect account because non-practiced categories had smaller set sizes.

Discussion

The findings of Experiment 2 independently replicate and extend those of Experiment 1. Specifically, while facilitation for practiced objects increased with additional practice until performance plateaued, there was no reliable effect on forgetting of related objects. In addition, forgetting did not reliably differ across three different set sizes. These results again demonstrate that recognition-induced forgetting is not due to the category-based set size effect but indeed due to recognition practice.

General discussion

Recently, Maxcey and Woodman (2014) showed that practice remembering a visual object was accompanied by the forgetting of related information that was learned at the same time. We called this effect *recognition-induced forgetting*. In the present study I sought to rule out an alternative explanation of recognition-induced forgetting. Specifically, that forgetting is due to category-based set size (Strong, 1912). To this end, across two experiments I parametrically manipulated the amount of practice objects received in the recognition-induced forgetting paradigm. Increasing practice trials for some objects also increases the set size of competitors for that object category. This is because recognition practice involves presenting two objects from the same category, the practiced object and novel lure from the same category (e.g., a novel chair). If the category-based set size effect explains forgetting, increasing set size should increase forgetting of related objects, as well as result in fewer correct rejections of novel test lures from that category. However, neither of these differences was significant, independently replicating and validating that the forgetting found by Maxcey and Woodman (2014) was indeed recognition induced.

Relationship between recognition-induced forgetting and retrieval-induced forgetting

The present study adds to two previous studies on recognition-induced forgetting to date (Maxcey & Bostic, 2015; Maxcey & Woodman, 2014). In this early stage of investigation, it is difficult to discern whether recognition-induced forgetting and retrieval-induced forgetting have independent or shared underlying mechanism(s). This is particularly true because the underlying mechanisms of retrieval-induced forgetting continue to enjoy heated debate (Murayama et al., 2014). However, the present study does appear to align properties of recognition-induced forgetting with certain properties of retrieval-induced forgetting.

First, two broadly different mechanistic perspectives have been set forth to account for retrieval-induced forgetting, the *inhibition-based account* and the *competition-based account* (Murayama et al., 2014). The competition-based account proposes that strengthening associations will yield additional interference. In the present study, support for this account would have involved worse memory for related objects as memory for practiced objects improved with increased practice trials. However, the present study showed that memory for related objects did not worsen as memory for practiced objects improved. On the other hand, the inhibition-based account argues that attempts to remember information activates multiple related memories, requiring that competing memories be suppressed to allow for the correct memory to be selected. This perspective can account for forgetting of related objects without requiring that the degree of forgetting be predictive of the degree of forgetting (unlike the competition-based account), a result shown in the present study. This parallel suggests that recognition-induced forgetting aligns nicely with the inhibition-based account of retrieval-induced forgetting.

Second, previous work on retrieval-induced forgetting has examined a property termed *strength independence*. This property refers to the idea that the degree to which practiced items are strengthened is not predictive of the degree of retrieval-induced forgetting (e.g., previous work on retrieval-induced forgetting has also dissociated the size of the remembering and forgetting effects of retrieval practice; Aslan & Bäuml, 2011; Hanslmayr, Staudigl, Aslan, & Bäuml, 2010; Hulbert, Shivde, & Anderson, 2012; Kuhl, Dudukovic, Kahn, & Wagner, 2007; Macrae & MacLeod, 1999; Staudigl, Hanslmayr, & Bäuml, 2010). Such strength independence is mimicked herein as increased memory for practiced objects was not directly predictive of forgetting of related objects, consistent with work by Norman and colleagues suggesting that moderate activation of a memory is sufficient for weakening of that memory representation, irrespective of the strength of competing items (Detre, Natarajan, Gershman, & Norman, 2013; Poppenk & Norman, 2014).

Future directions

Given that the experiments herein firmly establish that forgetting of objects in the Maxcey and Woodman (2014) paradigm is recognition-induced, future experiments measuring these effects in naturalistic settings are an important step toward understanding their real-world application. For example, it is not yet evident whether visual, semantic or episodic relatedness (or some combination of the three) is underlying recognition-induced forgetting. To begin to address this issue, future work will examine whether recognition-induced forgetting occurs for temporally related items. For example, does recognizing one class of objects (e.g., faces) lead to forgetting of an entirely different class of visual objects (e.g., weapons) if they are related by having appeared in a uniting episode (e.g., crime scene)? The real-world application of such forgetting is clear under circumstances such as eyewitness testimony and circumscribes important future work with this now well-established phenomenon.

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