Unintentional forgetting is beyond cognitive control

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Abstract

Intentional forgetting refers to the attempt to marshal top-down control to purposefully forget, and has been demonstrated in the laboratory using directed forgetting paradigms. Here, we asked whether the mechanisms of top-down control can run in the opposite direction to prevent the forgetting of information; that is, can we actively resist unintentional forgetting? Recognition-induced forgetting is an unintentional forgetting effect in which accessing one memory leads to the forgetting of related memories. Just as intentional forgetting possesses intuitively appealing control over eliminating undesirable memories, resisting unintentional forgetting over desired memories would improve cognitive performance. We showed subjects a 9-min video to teach them about the recognition-induced forgetting paradigm and how recognition of certain objects unintentionally leads to forgetting of semantically related objects. After testing their comprehension of the video, we conducted a typical recognition-induced forgetting experiment and challenged the subjects to resist this form of unintentional forgetting. Despite their knowledge of the forgetting effect, and the challenge to subjects to resist the forgetting induced by the paradigm, recognition-induced forgetting persisted. These results show that knowledge of this unintentional forgetting phenomenon and the challenge to resist forgetting do not eliminate it, suggesting that it is cognitively impenetrable.

Significance

Control over memory is critical to our daily lives. The ability to intentionally forget, as in expunging an unpleasant memory, has been demonstrated in the laboratory. Here we ask whether the same control can be exerted over unintentional forgetting. To this end, we employed a forgetting paradigm that unintentionally causes forgetting of information when a semantically related target is retrieved from memory. We trained subjects on this forgetting effect and instructed them to resist forgetting. We found that neither briefly trained, nor expert subjects who were offered a reward, could resist forgetting. These results suggest that, unlike the control we appear to have over intentional forgetting, unintentional forgetting is beyond our control. Evidence that awareness does not bolster immunity to unintentional forgetting calls for caution under a plethora of real-world cognitive tasks in which one of several semantically related memories is targeted, such as eyewitness testimony and education.

Introduction

Intentional forgetting refers to the attempt to marshal top-down control to purposefully forget and has been demonstrated in the laboratory using directed forgetting (MacLeod, 2012; Muther, 1965) and think/no-think paradigms (Anderson & Green, 2001). These laboratory tasks demonstrate appealing control over forgetting unwanted memories, such as an unpleasant encounter or an unwanted telephone call. Here we asked whether the mechanisms of top-down control can run in the opposite direction to prevent the forgetting of desirable memories, such as when studying for an examination or a vacation; that is, can we actively resist unintentional forgetting?

Here we use unintentional forgetting in reference to the incidental negative consequence of accessing a target memory, the forgetting of related memories (Anderson, Bjork, & Bjork, 1994; Maxcey & Woodman, 2014). Recognition-induced forgetting is a robust unintentional forgetting effect whereby practice in recognizing an item...
in memory leads to the forgetting of related items (Maxcey, 2016; Maxcey & Bostic, 2015; Maxcey, Bostic, & Maldonado, 2016; Maxcey, Glenn, & Stansberry, 2017; Rugo, Tamler, Woodman, & Maxcey, 2017). Although this unintentional forgetting may operate in real-world scenarios such as identifying suspects in a lineup or studying for an examination, the ability to exert executive control over this forgetting phenomenon has never been tested.

Despite arguments that forgetting is adaptive (Bekinschtein, Weisstaub, Gallo, Renner, & Anderson, 2018), one might argue that if it were possible to eliminate forgetting under circumstances in which we desired to remember, we would have already eliminated forgetting. Indeed, there is reason to believe that subjects cannot resist unintentional forgetting. First, the spreading activation nature of recognition-induced forgetting, in that the forgotten information is semantically related to a targeted memory, suggests forgetting may be automatic (Logan, 1988) and thus cognitively impenetrable. Second, manipulations to eliminate memory errors in another semantic-spreading task, the Deese–Roediger–McDermott paradigm, have been unsuccessful (McDermott, 1996). In the Deese–Roediger–McDermott task, subjects are presented with a list of semantically related words to remember (e.g., cookie, sugar). In a later memory test, subjects misreport semantically related lures (e.g., sweet) as having been on the list. Efforts to abolish this effect through repeating learned items are unsuccessful in eliminating this effect.

Conversely, there is reason to believe that subjects can resist unintentional forgetting. First, the ability to exert executive control over memory, as in directed forgetting tasks and their predecessors (Bjork, 1972; Bjork, Laberge, & Legrand, 1968; Brown, 1954; Epstein, 1972; MacLeod, 2012; Muther, 1965), suggests that some forgetting is under volitional control. Second, executive control appears to eliminate a related forgetting phenomenon, that of retrieval-induced forgetting (Imai, Kim, Sasaki, & Watanabe, 2014). Third, explanations of retrieval-induced forgetting have posited a role of executive control (Anderson, 2003), suggesting it may be possible to wield control over this effect. Fourth, the ability to exert top-down control over memory encoding has been frequently demonstrated (Adcock, Thangavel, Whitlefield-Gabrielli, Knutson, & Gabrieli, 2006; Gruber & Otten, 2010; Gruber, Watrous, Ekstrom, Ranganath, & Otten, 2013) and is reflected in the neural correlates of memory encoding (Sunby, Woodman, & Fukuda, 2019), suggesting that resisting recognition-induced forgetting may be possible.

Here we asked whether subjects were able to resist recognition-induced forgetting following instructions to do so. In Experiment 1, subjects were taught about recognition-induced forgetting and challenged to resist forgetting before completing the paradigm. In Experiment 2, subjects were naive to recognition-induced forgetting to provide a baseline measure of susceptibility to this forgetting effect. In Experiment 3, recognition-induced forgetting experts were challenged to resist forgetting. A unique aspect of our experimental design is that we were able to compare susceptibility to this unintentional forgetting effect between informed subjects (Experiment 1), naive subjects (Experiment 2), and expert subjects (Experiment 3).

**General methods**

The experiment began with the study phase (Fig. 1). Subjects were presented with 72 objects for 5 s each and instructed to remember each object for a later memory test. The objects were six objects drawn from 12 basic-level object categories.

Next, in the recognition practice phase, subjects completed an old–new recognition judgment task testing memory for a subset of the objects from the study phase. Specifically, half of the objects from half of the categories (3 objects × 6 basic-level categories = 18 objects total) from the study phase were presented twice during the practice phase (36 old trials). For a 50/50 old–new correct response distribution, 36 new objects were included in the practice phase. The specific objects practiced were counterbalanced across subjects. A 5-min delay interval during which the subjects completed a visual distractor task followed both the study and practice phases.

In the test phase, the subject’s task was the same as the practice phase, but the total object set differed. Subjects were presented with 36 old objects and 36 new objects from corresponding object categories. Old objects in the test phase included three object types. Practiced objects were shown in the study phase and practiced in the practice phase. When subjects encountered a practiced object in the test phase, they were seeing it for the fourth time. Related objects were from the study phase that were not practiced. However, they are categorically related to practiced objects (e.g., telephones were practiced but not this specific telephone). Baseline objects were also in the study phase but not the practice phase, just like related objects. The difference between related and baseline objects is that baseline objects were from categories that were not practiced (e.g., presents were not practiced). Memory for baseline and related objects is critical to the signature recognition-induced forgetting effect. Recognition-induced forgetting is when related objects are remembered at reliably worse rates than baseline objects (Maxcey, 2016; Maxcey & Bostic, 2015; Maxcey & Woodman, 2014; Maxcey et al., 2016, 2017; Rugo et al., 2017). The 36 old objects were evenly drawn from the three object types (i.e., practiced, related, and...
baseline) and the 36 new objects were drawn from corresponding basic-level object categories (e.g., an equal number of telephones).

**Experiment 1**

In Experiment 1, subjects watched a video describing how the recognition of certain objects unintentionally leads to forgetting of semantically related objects in the recognition-induced forgetting paradigm. Subjects were challenged to resist this forgetting before completing a recognition-induced forgetting experiment.

**Methods**

**Participants**

A pilot experiment run to determine the necessary sample size (Faul, Erdfelder, Lang, & Buchner, 2007) had a $d_z = 0.76$. If we wanted to have 95% power to detect an effect equal to this with a two-tailed t-test, we would require 25 subjects. A second power analysis was run over data from Experiment 1 of our original recognition-induced forgetting study (Maxcey & Woodman, 2014) resulting in $d_z = 1.376$. If we wanted to have 99% power to detect an effect equal to this with a two-tailed $t$ test, we would require 12 subjects. We ran 52 subjects knowing that we may lose subjects based on insufficient effort leading to chance performance.

Subjects were 54 Ohio State University undergraduates (mean age 19.09 years, 34 female, 20 male) who completed the experiment in exchange for course credit. The critical manipulation in this experiment relied on effortful participation, indicating that subjects whose memory for baseline objects at test were at or below chance should be excluded from analysis resulting in the loss of 16 subjects. The analysis presented here is comprised of the 38 remaining subjects (mean age 19.11 years, 24 female, 14 male). Subjects reported normal color vision and normal or corrected-to-normal visual acuity. Informed consent was obtained prior to the beginning of the experiment. All procedures were approved by the Institutional Review Board.

**Stimuli and apparatus**

Stimuli were presented on a white background on a flat-screen monitor using e-prime software (Schneider, Eschman, & Zuccolotto, 2012). The stimulus set consisted of pictures drawn from 12 basic-level object categories (e.g., an equal number of telephones).
categories with 15 exemplars from each category. The specific categories practiced were counterbalanced across subjects. Subjects reported whether the pictures were old or new during the recognition practice and test phases using a Chronos response box. Subjects were seated approximately 80 cm from the monitor in a dimly lit room. Stimuli subtended approximately 4.6° of visual angle.

Procedure
The procedure followed the general methods described above with the following exceptions. Before beginning the experiment, subjects watched a 9-min video describing the forgetting typically induced in the recognition-induced forgetting paradigm and challenging them to resist forgetting. Then subjects completed a quiz (Additional file 1) to confirm they comprehended the video before starting the experiment. Following the experiment, subjects completed a survey (Additional file 2) to inquire about strategy and effort.

Data analysis
The primary dependent variable for recognition memory is hit rate across the three main object types: practiced, related, and baseline. To provide converging evidence for hit rate analyses, in footnotes beneath the critical comparisons we report the discrimination measure (Pr) and the associated bias measure (Br) (Feenan & Snodgrass, 1990). All preplanned t tests with equal sample size are accompanied by scaled JZS Bayes factor (Rouder, Speckman, Sun, Morey, & Iverson, 2009). Significant t tests are accompanied by Cohen’s d measure of effect size. Individual subject data are discussed in Additional file 3.

Results
A repeated-measures analysis of variance (ANOVA) comparing the means for object type ($F (2,74) = 58.667, p < .001, \eta^2_p = .613$) indicated a reliable difference (Fig. 2; see Additional file 3 for individual subject data). Memory for related objects (.68) was worse than memory for baseline objects (.78, $t (37) = 3.421, p = .002, d = 0.58$, scaled JZS$_{ALT}^5 = 21.19$) and memory for practiced objects (.98) was better than baseline (.78, $t (37) = 8.313, p < .001, d = 2.14$, scaled JZS$_{ALT} = 20,198,134$). Despite learning about recognition-induced forgetting and instructions to resist forgetting, subjects were susceptible to forgetting. Importantly, forgetting was not induced by a build-up of interference from the presentation of foils across the test phase because recognition performance in the second half of the test phase (.84) was not reliably worse than the first half (.85, $t (37) = 0.819, p = .418$, scaled JZS$_{NULL} = 4.19$).

Discussion
Despite subject’s knowledge of recognition-induced forgetting, and the challenge to resist forgetting, recognition-induced forgetting persisted. These results show that knowledge of this unintentional forgetting phenomenon and the challenge to resist forgetting do not eliminate it, suggesting that it is cognitively impenetrable.

Experiment 2
In Experiment 2 we replicated the methods of Experiment 1 but without the instructional video to provide a baseline of the proportion of subjects that demonstrate forgetting in a typical recognition-induced forgetting experiment.

![Hit Rate for Old Objects](image)

**Fig. 2** Hit rate for old objects in the test phase by object type from Experiment 1. The x axis represents memory for baseline objects and error bars represent 95% confidence intervals as described by Cousineau (2005) with Morey’s correction applied (Morey, 2008).
**Methods**

**Participants**

Subjects were 54 Ohio State University undergraduates (mean age 19.23 years, 24 female, 30 male) who completed the experiment for course credit. To allow a comparison between experiments, the same exclusion criterion for chance memory performance was applied resulting in the loss of 15 subjects. The data reported here are from the remaining 39 subjects (mean age 19.13, 20 female, 19 male).

**Procedure**

The procedure was identical to Experiment 1 with the following exceptions. The video and quiz were not administered before beginning the experiment. A slightly different survey was administered at the end of the experiment (Additional file 4).

**Results**

A repeated-measures ANOVA comparing the means across object types \( F(2,76) = 71.740, p < .001, \eta^2_p = .654 \) indicated a reliable difference (Fig. 3; see Additional file 3 for individual subject data). Memory for related objects (.65) was worse than memory for baseline objects (.75, \( t(38) = 3.597, p = .001, d = 0.69, \) scaled \( \text{JZS}_{\text{ALT}} = 33.31 \)) and memory for practiced objects (.96) was better than baseline (.75, \( t(38) = 10.211, p < .001, d = 2.54, \) scaled \( \text{JZS}_{\text{ALT}} = 4,457,051,777 \)). As in Experiment 1, forgetting was not induced by interference because recognition performance in the second half of the test phase (.80) was not reliably worse than the first half (.81, \( t(38) = 0.095, p = .925, \) scaled \( \text{JZS}_{\text{NULL}} = 5.77 \)).

**Discussion**

Replicating Experiment 1 and other studies on recognition-induced forgetting, naive subjects were susceptible to forgetting. Taken together, Experiments 1 and 2 show that knowledge of the recognition-induced forgetting effect did not reliably decrease susceptibility to forgetting, suggesting this forgetting effect is robust and cognitively impenetrable.

**Experiment 3**

Although the post-video quiz in Experiment 1 indicated subjects understood recognition-induced forgetting, it is possible that training was insufficient to enable resistance to forgetting. Expertise in recognition-induced forgetting may eliminate susceptibility to the effect. To determine whether subjects with a thorough understanding of recognition-induced forgetting were immune to forgetting, we replicated Experiment 2 with undergraduate research assistants working on recognition-induced forgetting projects in our laboratory who were instructed to resist forgetting. These subjects served as experts who would have a better understanding of the effect than subjects in Experiment 1.

**Methods**

**Participants**

Subjects were 11 Ohio State University undergraduates (mean age 20.8, 8 female, 3 male) who worked in our laboratory and completed the experiment in exchange for the possibility of a pizza reward (see Procedure).

**Procedure**

The procedure is identical to Experiment 2 with the following exceptions. Subjects were members of our
laboratory who were experts on recognition-induced forgetting. Subjects were instructed to resist recognition-induced forgetting. Subjects were informed that if they successfully resisted forgetting, they would win a pizza reward.

**Results**

A repeated-measures ANOVA comparing the means across object type ($F(2,20) = 18.327, p < .001, \eta^2_p = .647$) indicated a reliable difference (Fig. 4; see Additional file 3 for individual subject data). Memory for related objects (.72) was worse than memory for baseline objects (.91, $t(10) = 4.202, p = .002, d = 1.36$, scaled $JZS_{ALT} = 25$), demonstrating recognition-induced forgetting with experts. Memory for practiced objects (.98) was not significantly better than baseline (.91, $t(10) = 1.910, p = .085, d = 1.02$, scaled $JZS_{ALT} = 1.2$), likely due to extremely high memory performance, indicative of effort to resist forgetting. Replicating Experiments 1 and 2, forgetting was not induced by interference because recognition performance in the second half of the test phase (.90) was not reliably worse than the first half (.91, $t(10) = 0.382, p = .711$, scaled $JZS_{NULL} = 3.16$).

**Discussion**

Despite extremely high baseline performance (.91) indicating a high degree of effort, expertise in recognition-induced forgetting did not eliminate the effect.

**General discussion**

Here we parametrically manipulated subject’s knowledge of recognition-induced forgetting, from naive subjects (Experiment 2) to subjects who received video training on recognition-induced forgetting (Experiment 1) and expert subjects (Experiment 3). We found that only a minority of subjects was immune to recognition-induced forgetting in each group. However, overall, all three groups of subjects were susceptible to the forgetting effect.

The inability to exert top-down control over recognition-induced forgetting is surprising for several reasons. First, numerous studies demonstrate the ability to exert control over memory encoding, by upregulating or improving memory for the targeted items (Adcock et al., 2006; Gruber & Otten, 2010; Gruber et al., 2013) and downregulating or forgetting targeted memories (Anderson & Hanslmayr, 2014; Gruber et al., 2013; MacLeod, 1998, 1999). Second, control over memory is even reflected in the neural correlates of memory encoding (Sunby et al., 2019). Third, demand characteristics would suggest numerous strategies for overcoming this forgetting effect, such as purposefully performing incorrectly for the practiced or baseline items to lower overall memory performance (but see Sunby et al., 2019 for data regarding the ability to voluntarily downregulate memory). Fourth, informing the subjects of the goals and methodology of many paradigms in cognitive psychology would presumably eliminate their effects (as in Simons, 2010). For example, giving subjects advance warning that there will be a surprise memory test for items they are told to forget in directed forgetting studies would presumably ameliorate forgetting. Warning subjects that the types of questions they are asked are meant to modify memory in classic false memory tasks would likely reduce or eliminate the rate of false memories. These examples of popular memory tasks that presumably rely largely on
subjects’ naivety illustrate the surprising and empirically useful persistence of recognition-induced forgetting in the present study.

This is the first experiment to test cognitive control over recognition-induced forgetting. We found that recognition-induced forgetting is cognitively impenetrable. These results are at odds with evidence that people can improve memory when offered a reward (Adcock et al., 2006; Gruber & Otten, 2010; Gruber et al., 2013; Imai et al., 2014) and when simply cued to try harder when encoding particular pictures (Sunby et al., 2019). In fact, improved memory for pictures preceded by a priority pre-cue is accompanied by electrophysiological markers of attentional resources (i.e., prestimulus occipital alpha power suppression and visually evoked N1; Sunby et al., 2019), demonstrating that it is possible to successfully exert cognitive control over memory encoding. The inability to resist forgetting here, despite the ability to exert control over information processing in general (Gaspelin, Leonard, & Luck, 2015, 2017; Hickey, Di Lollo, & McDonald, 2009; Noonan et al., 2016; Noonan, Crittenden, Jensen, & Stokes, 2018; Posner, 1980; Sawaki & Luck, 2011), indicate that models of forgetting need not involve executive control (Anderson, 2003; Kim, Lewis-Peacock, Norman, & Turk-Browne, 2014) but rather automatically likely plays a role (Logan, 1988) in weakening associated memories (Raaijmakers, 2018). These results also suggest that the robustness of this effect may increase its empirical utility. Outside the laboratory, knowledge of memory phenomenon, such as recognition-induced forgetting, may not improve cognitive functioning and performance in a wide range of real-world scenarios, from the law to education.

Endnotes

1The recognition-induced forgetting paradigm, by definition, presents additional novel pictures in the old–new recognition judgment task. Our laboratory has demonstrated that forgetting is not parametrically manipulated by set size, suggesting that forgetting is not due to retroactive interference but is indeed the result of recognition (Maxcey, 2016).

2Basic-level object categories included telephone, cake, present. Find the full stimulus set at https://osf.io/j47hz/?view_only=c7e130d1209d4683b1618d4f01a2e5d.

3https://www.youtube.com/watch?v=pRhece229Ets&feature=youtu.be

4Br values greater than 0.5 are indicative of a liberal bias while values lower than 0.5 indicate a conservative bias. When calculating Br, Pr values of 1 were changed to 0.99.

5JZS Bayes Factor provides a way of quantifying support for either the null or alternative hypothesis (Rouder et al., 2009). For example, here the alternative hypothesis is 38 times more likely to be true than the null. JZS\textsubscript{ALT} is a value in favor of the alternative and JZS\textsubscript{NULL} is a value in favor of the null hypothesis.

Additional files

| Additional file 1: | Experiment 1 post-video quiz (DOCX 599 kb) |
|-------------------|-------------------------------------------|
| Additional file 2: | Experiment 1 post-experiment survey (DOCX 17 kb) |
| Additional file 3: | Individual subject data. (DOCX 13 kb) |
| Additional file 4: | Experiment 2 post-experiment survey. (DOCX 13 kb) |

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Authors’ contributions

AMM conceived the study, programmed the experiments, analyzed the data, and drafted the manuscript. BD, EM, and AS created the video, collected the data, and revised the manuscript. EM also analyzed data. AS conceived Experiment 2. All authors read and approved the final manuscript.

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Availability of data and materials

The datasets analyzed during the current study are available from the corresponding author on reasonable request.

Ethics approval and consent to participate

All procedures were approved by The Ohio State University Institutional Review Board.
Consent for publication
Not applicable.

Competing interests
The authors declare that they have no competing interests.

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