In Press, Cognition (2013)

Reviewing erroneous information facilitates memory updating

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Reviewing information stored in memory will generally strengthen that information, so it seems reasonable that reviews should make it harder to replace the information in memory if it is later found to be erroneous. In Experiment 1, subjects learned 3 facts about each of 12 topics. On Day 2, the same facts were either reread, tested, or not reviewed; then the facts were "corrected" with new replacement facts. A test on the replacement facts given 1 week later disclosed that both rereading and testing the to-be-replaced Day-1 facts enhanced memory for the Day-2 facts which supplanted them, although rereading (but not testing) the Day-1 facts also led to more intrusions of Day-1 facts on the final test. In Experiment 2, subjects were unexpectedly asked (in the final test) to recollect both original and replacement facts; old facts were often retrieved, especially when reviewed. It is suggested that review may promote development of a secondary retrieval route for the corrected information.

Reviewing Erroneous Information Facilitates Memory Updating

People sometimes find that information they have stored in memory is erroneous, making it important to correct that information. What mental activity best allows this replacement to take place? At first blush, one might assume that reviewing the misinformation would be the very last thing one should do, since the review could only strengthen the erroneous information and make it harder to replace in memory. The question of whether this is so is the subject of the current article.

The question holds both practical and theoretical interest. From a practical standpoint, the need to overcome misconceptions is common and in some cases even vital. For example, science educators have long recognized the challenge of overcoming intuitive misunderstandings which students bring to many areas of science (Garrett & Fisher, 1926; Chi, Slotta, & Leeuw, 1994). Recently, Prasad, Gall and Cifu (2011) reported that of the articles published in 2009 in the *New England Journal of Medicine* that made claims about medical practice, 13% concluded that a reversal of current medical practice was called for. This implies that physicians cannot practice medicine effectively without frequently correcting information they have previously stored in memory when they learn that it has been overturned by subsequent research.

Theoretically, the question of whether information known to be erroneous is removed or overwritten in memory has been of interest for many years (Bjork & Woodward, 1973; Wilkes & Leatherbarrow, 1988; Seifert 2002), and may speak to very basic questions about the nature of memory traces and the processes that create and modify them. Additionally, within the cognitive neuroscience field there is growing interest in whether a phenomenon termed *reconsolidation* may underlie certain

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memory-correction phenomena in humans, as will be discussed further below.

In the remainder of the introduction, we describe a number of experimental results in the literature that have some bearing on how review or retrieval of memory contents might affect the ability to overwrite misinformation with new, corrective information. As we shall see, none provides any direct answers to the question posed here, but they do suggest alternative hypotheses and possible mechanisms.

Effects of Review/Retrieval on New Learning

How and why might review or retrieval of information affect the ability to overwrite it?

From an associationist perspective, the most obvious possibility would be that any intervention that strengthens an old memory will obstruct the storage of any potential competing associations. Reviewing memories generally strengthens them, and retrieving memories tends to strengthen memories more than merely restudying them (see Roediger & Karpicke, 2006, for a review).

On the other hand, the literature also contains some hints that when people learn information, testing that information may reduce the interfering effects observed upon subsequent learning. Tulving and Watkins (1974) taught subjects an A-B list of paired associates, followed by an A-C list. Different groups of subjects were tested on the first and/or the second list (immediately after the learning of the lists). Finally, after an intervening task, an MMFR-type test[1] was given, requiring subjects to try to recall both B and C items. When there had been no immediate test on either the B list or the C list, subjects recalled 24% of the C items in the final recall. This was boosted up to 44% when the B list had been tested. When the C list was also tested, testing of the B list as well improved the recall of C (raising it from 28% to 50%). Similar effects were found in a comparable within-subject experiment. Although the results appeared robust, the authors expressed puzzlement over their findings, saying "as far as we can tell there are no mechanisms postulated in the classical interference theories... that would prepare one for the observation that testing of recall of A-B pairs [promotes the] learning of A-C pairs." (p. 191).

Seemingly related effects have been observed more recently with recall of word lists. Szpunar, McDermott, and Roediger (2008) taught subjects multiple lists of words. Half of the subjects were tested on each list after it was presented, and the other half were not. Then all subjects were shown a final list of words and then tested on that list, and after a half hour, a final cumulative recall test (on all the lists) was given. Testing on all of the lists prior to the final list substantially enhanced recall of that final list, both on the test given immediately after study of the list and on the final cumulative test. Also, there were fewer intrusions of items from the earlier lists on the test of the final list. However, re-exposure to the prior lists, unlike testing, did not produce the effect. The authors concluded that testing has a powerful effect of "segregating" the lists.

Reconsolidation-Inspired Studies

Another potentially related set of studies has been inspired by the phenomenon of reconsolidation. This refers to the observation (chiefly seen in animal studies) that activating a memory (by placing a rat who had been trained in a maze back into the maze) launches a cascade of intracellular events paralleling those occurring after initial formation of memories, rendering the memory trace labile and vulnerable to time-dependent interference from receptor antagonists (e.g., Przybyslawski & Sara, 1997).

[1] This refers to a test in which people are given the stimulus term (A) and asked to produce both of the response terms (B and C) as best they can.

Aiming to construct a human analogue of the reconsolidation effect, Hupbach, Gomez, Hardt, and Nadel (2007) had students interact with a set of objects on Day 1, placing them in a basket. On Day 2, some were given a reminder of the general episode (without however recalling the specific objects), and then interacted with a second set of objects. On Day 3, subjects were given a test requiring them to try to report as many objects as possible from the set they encountered on Day 1. The subjects who were given a reminder of the first session on Day 2 tended erroneously to report items from the Day-2 list. There was also a reduction in the number of Day-1 items reported on the final test, although this reduction was not significant. A subsequent follow-up study by Hupbach, Gomez, and Nadel (2009) used a final recognition test, and found that the Day-2 reminder of the initial exposures to objects produced a tendency to mis-report Day-2 items as having been presented on Day 1.

Implications

Based on the diverse sets of studies described above, one can envision a number of hypotheses about how reviewing some factual information might potentially affect the later processing and storage of replacement information. Given the results of Tulving and Watkins (1974) and Szpunar et al. (2008), it might be that testing (but perhaps not rereading) information to be corrected might render it less likely to interfere with contradictory information to be learned later. The mechanisms for this are not clear, but it seems conceivable that retrieval might strengthen linkages between the memory contents and the context in which they were encoded (something that may be used as a retrieval cue), and this in turn might reduce the confusability of the two sets of information (cf. Jang & Huber, 2008). Alternatively, if Hupbach, Nadel and colleagues are correct that reminding of a previous encoding event triggers reconsolidation which renders the old traces more malleable, this might directly facilitate corrective learning.

Current Research

The goal of the current studies is to ask how review or retrieval of previously learned factual information affects the ability to acquire new information which contradicts the initially learned informed. Factual information was used rather than word lists, along with nontrivial retention intervals, in order to insure that the results would have direct relevance to correction of misinformation in real-world settings. Within each of the studies presented below, we also compared the effects of reviewing information with the effects of testing this information. To make the time intervals meaningful, subjects performed three sessions, occurring on Days 1, 2, and 8, with the presentation, review and correction all taking place on the first two days.

Experiment 1

What happens when new information is learned that should supplant prior factual information in memory? We designed an experiment in which subjects were taught 36 facts (3 facts about 12 topics) on Day 1. On Day 2, some of the facts learned on Day 1 were reviewed (either through testing or through re-presentation). Then, subjects were told that the facts they had learned (and in some cases reviewed) were incorrect, and that they needed to be supplanted with new (correct) facts about the same things. (One could construe this instruction as a directed or intentional forgetting manipulation; see MacLeod, 1998, for a review of the experimental literature on directed forgetting.)

Method

Subjects. 56 undergraduate students from the University of California, San Diego, participated in return for course credit.

Design. A within-subjects design was used. Facts about 12 fictitious topics were assigned to each of the three different experimental conditions. The three conditions were Reread, Test, and Control. For four of the topics, all of the facts about these topics that had been presented on Day 1 were reread on Day 2. For another four of the topics, all the facts presented on Day 1 were tested on Day 2. For a final four topics, there was no review on Day 2. The assignment of topics to condition was counterbalanced across subjects.

Materials. A set of Day-1 and Day-2 facts (36 for each day) was created (see Table 2 for examples).

Procedure. Figure 1 shows an overview of the procedure. On Day 1, subjects were told that they would be learning some fictitious facts, and that they should pay close attention to them because they would receive a small bonus for all the ones they were able to retrieve later ($0.20 per fact). Subjects were presented with 3 facts each about 12 different topics (Day-1 facts), and each set of 3 facts (accompanied by the name of the topic) was shown on the screen for 18 seconds. The presentation cycled through the list twice in a different individually randomized order.

On Day 2, the items assigned to the reread or retrieve conditions were reviewed. In the reread condition, subjects were told that they would see facts they had been taught the previous day (i.e., Day-1 facts), and should again try to study them to maximize their later memory for them. The items were presented at a rate of 18 seconds per triplet. In the retrieve condition, the subject was shown the names of the four topics one at a time. The computer provided 3 blanks in which the subject could type in the Day-1 facts they remembered, and subjects proceeded at their own pace. Feedback was not provided. After the review of the 24 Day-1 facts (12 reread, 12 tested), subjects were told "You've now had the chance to review some of yesterday's information. ... We are interested in how people update their knowledge (i.e., replace old, outdated information with new information). [The facts you learn now] will contradict the details (about each item) that you learned yesterday. ... Your job is to try to learn these new details as best as you can, and forget about the old details you learned." They were also told that they would receive $0.40 (instead of $0.20) for each of the new facts they were able to remember. The instructions concluded with an exhortation that "The old information you learned yesterday is no longer relevant, so it will be to your benefit if you forget the old information and replace it with the new information you are about to see." There were two cycles through the list (of replacement facts), again at a rate of 18 seconds per triplet.

In the final session (Day 8), subjects were reminded of the bonuses, and tested on each set of facts one at a time, with a probe naming the topic (e.g., "Golden-Eared Marmoset") and 3 blank response fields for the subject to type in their responses. The 12 topics were tested in a random order, and testing was self-paced. It was stressed that they were to recall only the replacement facts taught in Session 2. ("Do not respond with details that you learned on Day 1.")

Results and Discussion

Subjects' responses were scored by a single rater that was blind to the condition each item was assigned to. Each fact that was correctly recalled was awarded 1 point, and partial credit was given for partially correct responses (0.5 points). To assess the reliability of the scoring, all responses were scored independently by a second rater.. There was very high inter-rater agreement between the first and second rater (Cohen's kappa = 0.95), and all analyses reported here are based on scoring by the first rater. The α-level for all analyses was set at .05.

Figure 2 shows the mean proportion of Day-2 facts recalled on the final test as a function of condition, along with the proportion of intrusions (i.e., proportion of

Day-1 facts recalled). There was an effect of review condition on correct recall of Day-2 facts, F (2, 110) = 7.52, $\eta_p^2 = .12$. Pairwise comparisons showed better memory for Day-2 facts in the reread and test conditions compared to the control condition, ts > 3.33, ds > 0.44, but no reliable difference between the reread and test conditions ($t < 1$). There was also an effect of review condition on the amount of Day-1 facts recalled by mistake, F (2, 110) = 9.48, $\eta_p^2 = .147$. Pairwise comparisons revealed the reread condition had a higher number of intrusions of Day-1 facts than either the test or control condition, ts > 3.02, ds > 0.40, but the difference between the latter two conditions did not reach significance, $t(55) = 1.25$, $p = .217$.

The results show that reviewing the Day-1 facts, whether it takes the form of rereading or responding to a recall test, enhances memory for the replacement Day-2 facts. Moreover, for the test condition at least, there does not seem to be any corresponding increase in the rate of intrusions of Day-1 facts--so the testing review actually enhances both the availability and the selectivity of the memory for Day-2 materials. There was no detectable difference between performance in the rereading and the testing condition as implemented here. (As an anonymous reviewer points out, it is certainly possible that if the level of performance on the test had been different, there might have been a significant difference.)

Table 2 shows accuracy and intrusion rates for the final test, conditionalized on performance on the Day-2 test. Recall performance on Day 2 was positively associated with accurate recall of the replacement facts on the final test, F (2, 90) = 10.492, $\eta_p^2 = .189$. Items successfully retrieved on Day 2 were associated with higher recall of the replacement facts on the final test than items only partially retrieved on Day 2 (.61 vs. .48), $t(48) = 2.31$, $p = .025$ (uncorrected), $d = 0.33$. Similarly, items partially retrieved on Day 2 were associated with higher final recall of the replacement facts than items that were unretrievable on Day 2 (.48 vs. .35), $t(45) = 2.35$, $p = .023$ (uncorrected), $d = 0.35$. (In the analyses just reported, differences in the degrees of freedom are due to varying numbers of subjects contributing to the analyses, depending on whether they had data in the relevant cell.) The fact that better recall on Day 2 predicted more successful correction is intriguing, and reminiscent of the *hypercorrection effect* reported by Metcalfe and Finn (2011). That phenomenon refers to the fact that for learners who experience corrective feedback, errors that are made with high confidence tend to be easier to correct than errors made with low confidence.

(In a companion experiment that is not reported here for the sake of brevity, we used a virtually identical procedure, except that the additional facts learned on Day 2 were complementary, rather than contradictory, facts about the same topics. In this case, reviewing the earlier-learned information on Day 2 had no detectable benefits or cost for recall of the new information on Day 3. Details are available at Pashler, Kang, and Mozer, 2013.)

Experiment 2

Experiment 2 mirrored Experiment 1 in terms of materials, instructions, and procedure for the first two sessions. However, on the final session, subjects were told that they should try to recollect facts from both Day 1 and Day 2 (akin to the MMFR test used by Tulving and Watkins, 1974). This experiment had 69 subjects that were recruited from the same pool as the previous experiment (but had not participated in that experiment).

Results and Discussion

Subjects' responses were scored in the same way as in the previous experiments. There was very high inter-rater agreement between the first and second rater (Cohen's kappa = 0.94), and all analyses reported here are based on scoring by the first rater.

Figure 3 shows the accuracy in recall of Day-1 and Day-2 facts in Experiment 2. The results involving Day-2 facts replicate the beneficial effect observed in Experiment 1 from reviewing Day-1 facts on Day 2. There was a main effect of review condition on recall of Day-2 facts, F (2, 136) = 3.81, η_p^2 = .053. Pairwise comparisons indicated that both the test and reread conditions had higher recall than the control condition, ts > 2.24, ds > 0.27, while there was no difference between the test and reread conditions (t < 1). The results also show that the review is enhancing later memory for the Day-1 facts. There was a main effect of review condition on recall of Day-1 facts, F (2, 136) = 28.45, η_p^2 = .295. Pairwise comparisons confirmed that both the test and reread conditions yielded higher recall than the control condition, ts > 6.37, ds > 0.76, but performance was not different between the test and reread conditions (t < 1). Table 1 (bottom half of the table) shows accuracy for both Day-1 and Day-2 facts on the final test in Experiment 2, conditionalized on performance on the Day-2 test. The results mirror those of Experiment 1, showing that accurate recollection of Day-1 facts on Day-2 predicts final test memory for both old and corrective facts.

The results clearly show that in many cases the Day-1 facts coexist alongside the Day-2 facts in memory despite the instructions at encoding to treat the Day-2 facts as corrective information. This is broadly consistent with some prior studies of the correction of misinformation (e.g., Wilkes & Leatherbarrow, 1988; Johnson & Seifert, 1994, 1998; Seifert, 2002). It is also somewhat reminiscent of the observation that in directed forgetting experiments, to-be-forgotten materials are sometimes recognized well (Block, 1971).

General Discussion

The basic question posed in this paper was what effect reviewing facts (by either rereading the fact, or undergoing a test) would have on the storage of new facts. In Experiment 1, when the new facts were to replace the old facts, review of the old facts improved storage of the new.

This finding appeared to us to be quite counterintuitive; if one assumes that review strengthens memory traces, and that the old facts are strengthened, there is more opportunity for them to interfere with the new. To ascertain whether the result truly runs counter to common intuitions, we presented an overview of the basic design of Experiment 1 to a new set of 181 subjects recruited on Amazon Mechanical Turk. These participants were asked to pick between three choices: (1) *Reminding myself of the old, erroneous information by re-exposing myself to the erroneous information (e.g., reading about the fact that many people think that Australia's capital is Sydney, or being tested on recollecting the erroneous information) will help me to learn the corrected information.* (selected by 35%, or 64 out of 181) (2) *It will be better not to remind myself of the old, erroneous information (so as not to be confused later about which piece of information is correct / wrong).* (selected by 48%, or 87 out of 181); and (3) *Reminding myself of the old, erroneous information will not have any effect on my learning of the new corrected information.* (17%, or 30 out of 181) The results show that, as we expected, a distinct minority of subjects (about 1/3) correctly anticipated the finding.

Why should there be a moderately sized enhancement in the learning of new corrective facts following review of the to-be-replaced old facts? One possible account would cite reconsolidation as a factor. In the line of studies mentioned in the introduction, Hupbach and colleagues (e.g., Hupbach et al., 2007) found effects of a "reminding" procedure that they attributed to reconsolidation. In their designs, the reminding was global (it pertained to the entire preceding learning session, not just an individual fact that had been learned in that session). If reconsolidation operates at a global level as these authors postulated, then it would not be a likely candidate to account for the effects observed here. However, the authors do not appear to have tested for item-specific effects, and their results are consistent with the possibility that there might be both set- and item-level effects (with the latter possibly outweighing the former).

The results of Experiment 2 do not, however, fit with the view that reminders of the learning from Day 1 is causing the traces to be overwritten by the new learning. The results of this experiment showed that when subjects were asked to retrieve on the final test what they had learned in Day 1 as well as what they had learned in Day 2, they were generally quite well able to recollect the Day-1 facts and that this ability was enhanced, not reduced, by review of the Day-1 facts. Thus, if the reconsolidation theory is interpreted as postulating that review makes the memory trace plastic and vulnerable to being overwritten, then the current situation does not seem to reflect such a mechanism.

There are a number of studies in the cognitive and social-psychological literatures that documents cases in which information, though labeled as an error, continues to affect later judgments and attitudes. For example, Wilkes and Leatherbarrow (1988) showed that a statement that was labeled erroneous continued to drive inferences (see also Seifert, 2002). The finding that designating a Day-1 fact erroneous does not make it disappear is congeniel to this broader literature.

We are back, then, to the question of why review or testing of the Day-1 fact should make people better able to store and retrieve a new, contradictory fact. The explanation that strikes us as most plausible is that the Day-1 fact, when retrieved, often provides an additional retrieval pathway to facilitate recall of the Day-2 fact. This "extra mediator" account might operate because associations are formed between the corresponding Day-1 and Day-2 facts, simply due to the fact that both have common elements (and, in the Review conditions, both are activated close together in time). In addition, however, when the Day-2 fact is presented and people contemplate the falsity of the Day-1 fact, they may elaborate on the connection between the two facts.

Also of interest is the difference between the Testing and Restudy conditions. Restudy seems to have resulted in more intrusions of the (incorrect) Day-1 facts on final recall One interpretation would be that testing of the Day-1 facts might have added more contextual elements associated with those items (more so than rereading; Postman & Keppel, 1977), thus facilitating later source discrimination on the final test (Johnson, Hashtroudi, & Lindsey, 1993). This is consistent with some theoretical accounts of the "hypercorrection effect" (Metcalfe & Finn, 2011), which suggest that the emotion of surprise may be accompanied by enhanced encoding of the surprise-producing information. It is also possible that learning the falsity of previously acquired information generates a greater degree of curiosity about the truth of the matter (see also Berlyne, 1966).

As a reviewer pointed out, it would be interesting to know whether the results would be similar if individual items on a given topic were subject to a different level of review (in the current study, all 3 facts on a given topic were, as a whole, tested, reread, or not reviewed.) We would guess that the effects are item-specific (not just at the broader "topic" level.) The conditional analysis seems to back that up: the better the subject could retrieve a Day-1 fact, the more likely s/he would learn (and later retrieve) the new Day-2 fact. So it seems plausible that the results would have been unchanged if each of the facts were subjected to a different treatment--however, this point would need to be checked before this conclusion can be regarded as certain.

From a practical standpoint, the results suggest that reviewing previously taught misinformation may be a useful intervention to promote correction of this misinformation. Indeed, there has been some classroom research that is at least consistent with this. In the context of introductory psychology instruction, Kowalski and Taylor (2009) compared what they called "refutational lectures" (in which popular misconceptions about psychology, such as the "Mozart Effect" were specifically discussed, along with evidence opposing them) with more standard presentations of the same content, and found that the refutational approach resulted in students having better access at the end of the course to the correct information. These refutational lectures probably included other memorable elements besides mere review of the misinformation (e.g., discussion of the popular impact of the misinformation, and possibly humorous discussion of how the popular press had presented the misinformation), but the much more fine-grainbed results of the current study suggest that simply reviewing misinformation may facilitate the later retention of corrective information.

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This work was supported by a collaborative activity award from the J.S. McDonnell Foundation, the Institute of Education Sciences (US Department of Education, Grant R305B070537 to H. Pashler), the National Science Foundation (Center Grant SBE-0542013, G.W. Cottrell, PI), and the Office of Naval Research (Contract N00014-10-1-0072). We thank David Yee for programming the experiments and Noriko Coburn, Tiffany Nguyen, Judy Huang, and Lauralynn Pasion for assistance in data collection and scoring. The authors are grateful to Ken Norman and Jeff Karpicke for useful comments on previous versions of this manuscript.

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Table 1. Examples of Facts used in Experiments

Topic: Golden-Eared Marmoset

Day 1 Fact	Day 2 (Replacement) Fact
found only in Malaysia	found only in Brazil
diet mainly consists of beetles	diet mainly consists of tree sap
main predator is the tiger	main predator is the snake

Topic: Chef Leonardi Franco

Day 1 Fact	Day 2 (Replacement) Fact
famous chef in Italy	famous chef in France
parents were chefs	parents were teachers
received his culinary training from from parents	received culinary training at the Cordon Bleu

Table 2. Final recall conditionalized on performance in the initial (Day-2) test.

Experiment 1

	Correct (Day 2 Facts)	Intrusions (Day 1 Facts)
Completely Wrong on Initial Test	.35	.02
Partially Correct on Initial Test	.48	.07
Completely Correct on Initial Test	.61	.11

Experiment 2

	Correct (Day 2 Facts)	Recollections of Day 1 Facts
Completely Wrong on Initial Test	.26	.20
Partially Correct on Initial Test	.40	.47
Completely Correct on Initial Test	.54	.84

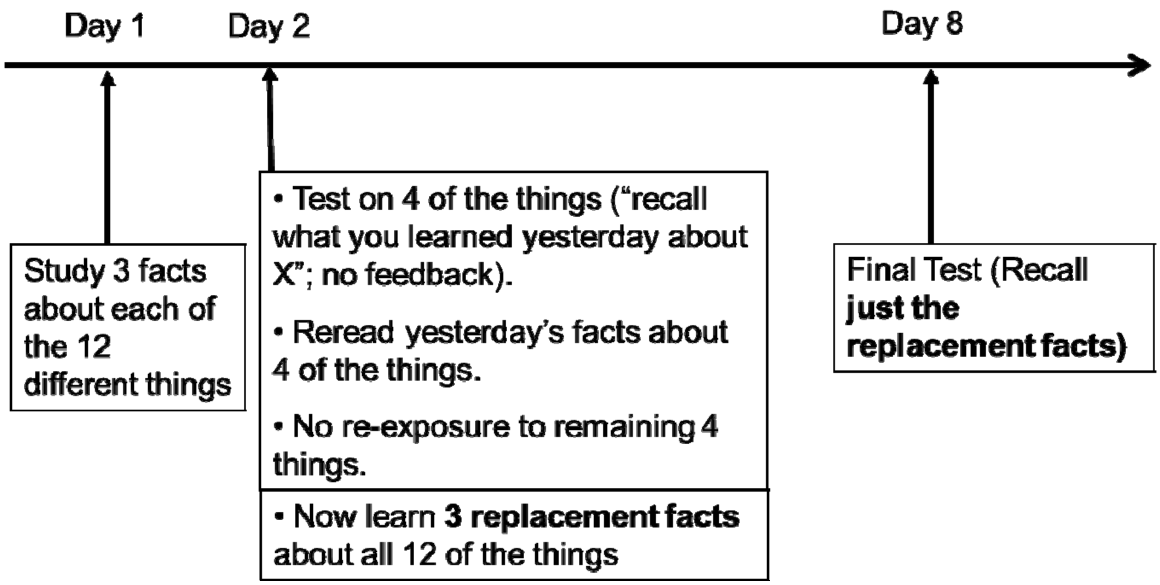

Figure 1. Schematic of procedure in Experiment 1.

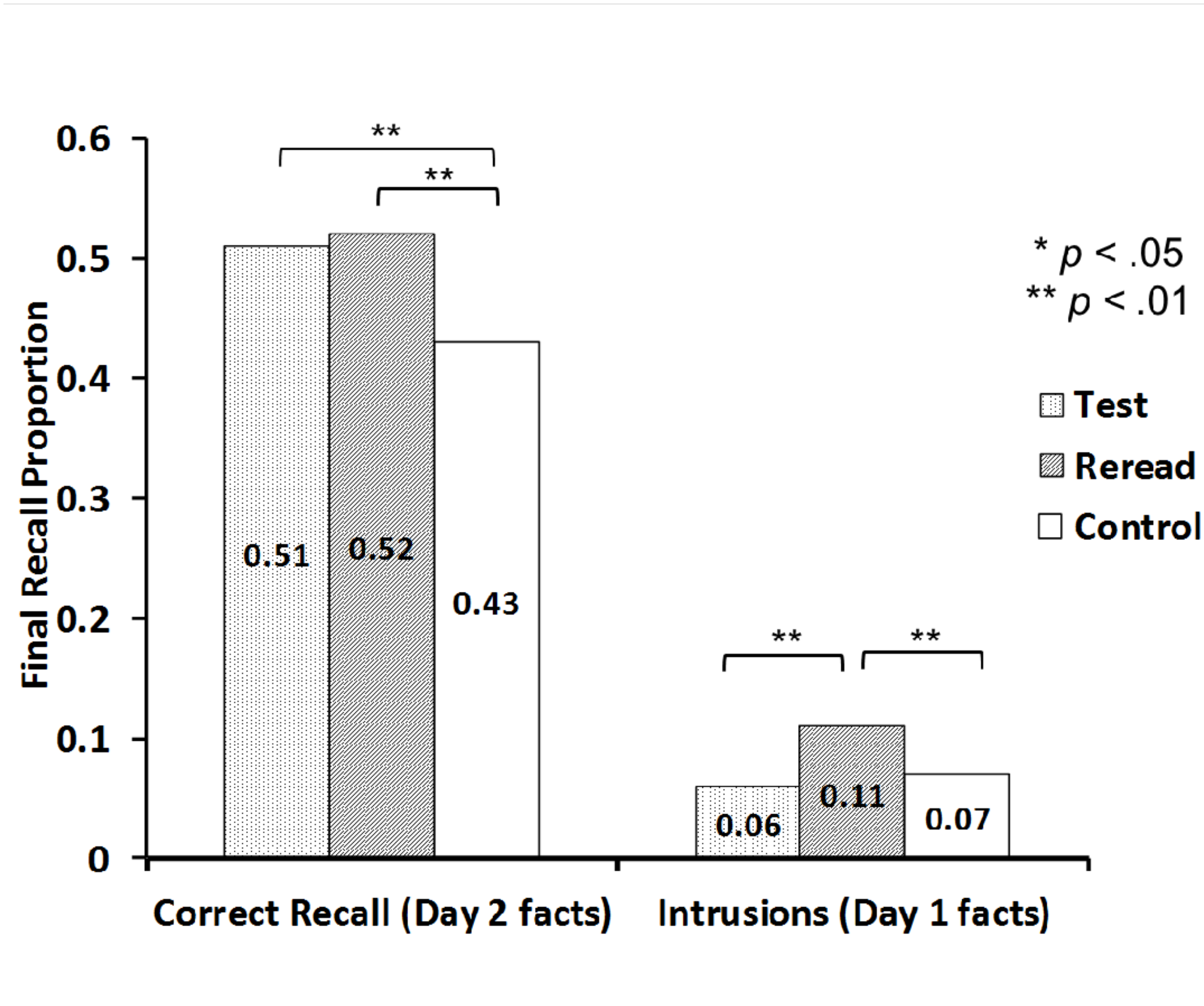

Figure 2. Mean accuracy on the final test for Experiment 1 as a function of whether the fact was first taught on Day 1 or Day 2, and condition (Test, Reread, or Control).

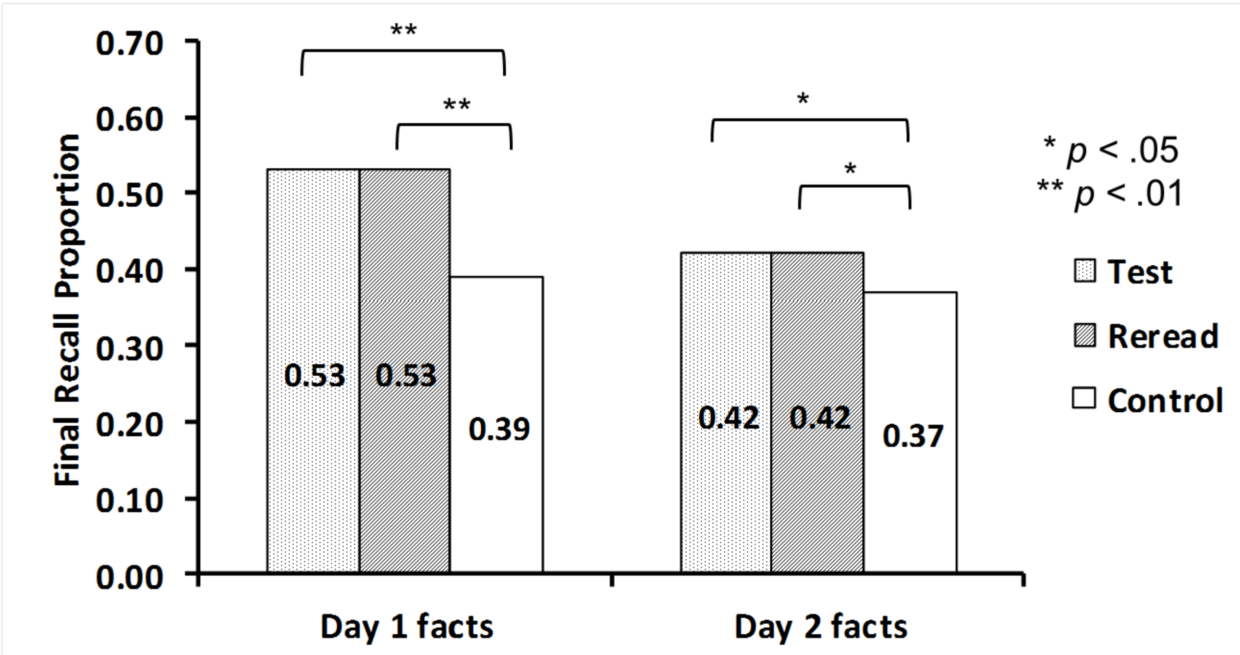

Figure 3. Mean accuracy on the final test for Experiment 2 (procedure was the same as Experiment 1 except that on Day 8, subjects were told to try to recall both Day-1 and Day-2 facts).