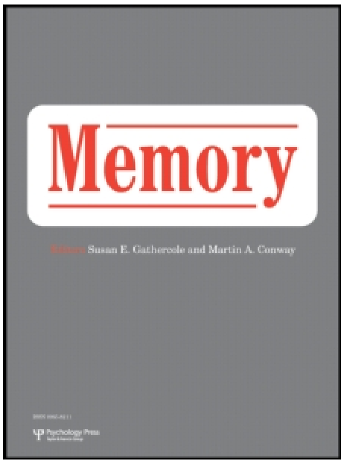

Memory
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t713683358

Episodic memory reconsolidation: Updating or source confusion?

Almut Hupbach [a]; Rebecca Gomez [a]; Lynn Nadel [a]
[a] The University of Arizona, Tucson, AZ, USA

First Published on: 26 May 2009

To cite this Article Hupbach, Almut, Gomez, Rebecca and Nadel, Lynn(2009)'Episodic memory reconsolidation: Updating or source confusion?',Memory,17:5,502 — 510

To link to this Article: DOI: 10.1080/09658210902882399

URL: http://dx.doi.org/10.1080/09658210902882399

MEMORY, 2009, 17 (5), 502–510

Psychology Press
Taylor & Francis Group

Episodic memory reconsolidation: Updating or source confusion?

Almut Hupbach, Rebecca Gomez, and Lynn Nadel
The University of Arizona, Tucson, AZ, USA

Reactivation of apparently stable, long-term memory can render it fragile, and dependent on a re-stabilisation process referred to as ''reconsolidation''. Recently we provided the first demonstration of reconsolidation effects in human episodic memory (Hupbach, Gomez, Hardt, & Nadel, 2007; Hupbach, Hardt, Gomez, & Nadel, 2008). Memory for a set of objects was modified by the presentation of a new set, if and only if participants were reminded of the first learning episode before learning the new set. The present study asks whether this effect can be interpreted as a source discrimination problem; i.e., participants have difficulties remembering which objects were presented during which session, and do not actually incorporate new objects into the reactivated memory. The present study used a recognition test and asked participants directly about the source of their memories. Participants in the no-reminder group showed very few source errors. Participants in the reminder group misattributed the source of objects from the second set as being from the first set but not vice versa, thus demonstrating updating of the original memory. This finding is informative with respect to the misinformation paradigm, and reconsolidation is discussed as a possible mechanism underlying our results and the misinformation effect.

Keywords: Memory reconsolidation; Source memory; Recognition; Misinformation effect.

New memories are initially fragile. This fragility is presumed to be gradually eliminated by a time-dependent memory consolidation process (e.g., McGaugh, 2000). The view of consolidation as an irreversible process has been challenged by the finding that when memories are reactivated they become fragile again and require a re-stabilisation process that has been called memory ''reconsolidation''. In recent years this phenomenon has been extensively studied in animals, and it is clear that memories can be modified long after they are acquired (e.g., Nader, 2003).

We recently developed a paradigm to study reconsolidation in human episodic memory (Hupbach et al., 2007, 2008). In this paradigm, participants learn a set of objects. Then 48 hours later, they are either reminded of the learning session or not, and learn a second set of objects under slightly different encoding conditions. After another 48 hours, participants are asked to recall the first or second set only. We found that reminded participants showed a high number of intrusions from Set 2 when recalling Set 1, while participants who were not reminded showed almost no intrusions. Importantly, when participants were asked to recall Set 2, reminded and no-reminded participants showed almost no intrusions. We interpreted the intrusions from Set 2 into Set 1 in the reminder group as evidence for memory updating: when Set 1 was reactivated during Session 2, memory for Set 1 re-entered a vulnerable state in which new objects could be incorporated, an interpretation that is in line with the reconsolidation account.

Address correspondence to: Dr Almut Hupbach, Department of Psychology, The University of Arizona, Tucson, AZ 85721, USA. E-mail: ahupbach@email.arizona.edu

We thank Amanda Brewer, Rabiah Muhammad, and Michael Weiss for helping with data collection. This research was funded by NSF grant BCS-0743988. We thank Marcia Johnson and an anonymous reviewer for their insightful comments.

http://www.psypress.com/memory DOI:10.1080/09658210902882399

However, by simply asking participants to recall the objects from either the first or second session, we do not know whether they closely monitored the source of the remembered objects. Source monitoring is an active reconstruction and decision process, whereas item memory itself can be based on familiarity or feeling of knowing, and does not necessarily involve a careful source evaluation (Johnson, Hashtroudi, & Lindsay, 1993).

Additionally, we did not assess memory for Set 1 and 2 simultaneously, which might have further discouraged careful source evaluation. Several studies show that the test format significantly affects source memory. Our paradigm is similar to the misinformation paradigm (e.g., Loftus, 1975; for a recent review see Loftus, 2005) in which participants are presented with a complex event (e.g., a slide show depicting a car accident) and later receive some misleading information about the event (e.g., about the traffic sign that marked the intersection). When asked to remember the original event, participants often falsely report the misleading detail (e.g., a yield sign) instead of the information that was part of the slide show (e.g., a stop sign). This misinformation effect might reflect an alteration of the original memory trace by the interpolated misleading information; alternatively it might reflect a source discrimination error where participants falsely attribute the origin of the misleading information to the slide show. Of relevance to the work reported here, Lindsay and Johnson (1989a) showed that this misattribution is reduced when participants are engaged in more stringent source evaluation processes. Participants intruded information that was only verbally suggested to them when a yes–no recognition paradigm was used that required only the identification of previously seen information. However, the misinformation effect was abolished altogether when participants were asked to identify the source of their memory for each recognised item (see also Dodson & Johnson, 1993; Zaragoza & Koshmider, 1989). This was interpreted as reflecting the stricter decision criterion employed in the source choice condition, which not only affects the amount of evidence that is reviewed but also the nature of evidence assessed, and how this evidence is weighed. Based on these findings, if our effects depend on source confusion we might expect to find a significant reduction in intrusions from Set 2 into Set 1 (which would be reflected in few source misattributions for Set 2 objects) when we assess source memory directly.

The present study aims to evaluate the contribution of source memory difficulties to the memory updating effect by using a source-monitoring paradigm. If reminded participants misattribute the source for Set 2 objects but not Set 1 objects, the reconsolidation explanation of our previous study would be strengthened. Other outcomes, such as a general source confusion (affecting Set 1 and Set 2) or an overall reduction of source errors, would suggest that our memory updating effect might reflect the lack of careful source evaluation at test.

EXPERIMENT 1

Method

Design and participants. The only independent variable that was varied between participants was the procedure during Session 2 (see below): Before being shown a second set of objects to remember, participants were either reminded or not reminded of the learning session that had taken place 2 days earlier (*reminder* and *no-reminder group*, respectively).

A total of 20 undergraduate students from the University of Arizona participated in the experiment. They received course credit for participation. A total of 10 participants were randomly assigned to each condition.

Materials. The following objects were presented in Session 1: balloon, bow, calculator, toy car, crayon, cup, dice, feather, flashlight, flower, glue, key, sock, sponge, spoon, sunglasses, teabag, tennis ball, toothbrush, whistle. The following objects were presented in Session 2: apple, band-aid, battery, book, cassette tape, cellular phone, comb, dollar bill, toy elephant, envelope, paper clip, toy pot, puzzle piece, rock, straw, thread, tissue, watch, toy shovel, zipper. The names of these objects and the names of the following 20 new objects were used in the recognition task: banana, bracelet, CD, chopstick, clothes pin, coin, cotton ball, credit card, eraser, light bulb, leaf, lipstick, magnifying glass, paint brush, scissors, stamp, stapler, teddy bear, washcloth, wrapping paper.

Procedure. Participants participated in three sessions (on a Monday, Wednesday, and Friday) separated by 48-hour intervals.

All participants learned a set of 20 unrelated objects during Session 1. In front of the participants, the objects were taken out one by one from a bag in a random order and placed into a distinctive blue basket. The participants' task was to name each item. After the presentation, participants were asked to recall as many objects as possible. If they recalled less than 17 objects, the objects were presented again and participants were asked to name them. This procedure continued until participants could recall at least 17 objects or until a maximum of four learning trials was reached.

The procedure during Session 2 differed for the reminder and the no-reminder group. For participants in the *reminder group*, the same experimenter who administered the procedure during Session 1 showed them the empty blue basket and asked, "Do you remember this basket and what we did with it?" Participants were encouraged to describe the procedure (as intended, they did not spontaneously recall specific objects from Set 1).[1] After that, the blue basket was put out of sight. For participants in the *no-reminder group* a new experimenter administered the experimental procedure in a different room. The experimenter did not ask what had happened during Session 1 nor did she present the basket. Participants in both groups were asked to learn a second set of 20 objects. In both groups the procedure differed from that of Session 1 so the task would not serve as a reminder. The objects were placed all at once on a table in front of the participants, who were asked to name each of the objects in any order, and after naming were given 30 additional seconds to study them. The experimenter then removed the objects, and asked the participants to recall as many of the objects as possible. If participants recalled fewer than 17 objects, the objects were placed in front of the participant for another 30 seconds. This was repeated until participants recalled at least 17 objects, or for a maximum of four learning trials.

During Session 3 the experimenter from Session 1 administered the recognition/source memory task in the room in which Session 1 had taken place. The experimenter named the objects from Set 1 and 2 and the new objects in a randomised order with the restriction that no more than three items from one set were named in succession, and asked the participant to first indicate whether the object was an old or a new object. For objects declared as old, the experimenter further asked whether the object had been presented on Monday (Session 1) or Wednesday (Session 2), and additionally how confident they were in the source judgement. For the confidence rating, a rating scale was placed in front of the participants, ranging from 1 to 5, with 1 labelled "not sure", 3 "somewhat sure", and 5 "absolutely sure" (2 and 4 were not individually labelled).

[1] We did not want participants to recall objects from Set 1 in order to avoid confounding possible updating with testing effects (e.g., Carrier & Pashler, 1992; Roediger & Karpicke, 2006).

Results

Recognition memory was excellent in both groups (see Table 1). Because Hit and Correct Rejection rates were at ceiling, and Miss, and False Alarm rates were at floor levels in both the reminder and the no-reminder group, we did not further analyse these scores.

The results of the source memory task are depicted in Figure 1. Source memory was analysed in two separate ways. The mean number of objects for which the source was correctly remembered was analysed with a 2×2 mixed ANOVA with group (reminder vs no reminder) and set (1 or 2) as the independent variables. The main effect of set, $F(1, 18) = 14.95$, $MSE = 4.02$, $p < .01$, and the interaction between group and set were significant, $F(1, 18) = 4.54$, $MSE = 4.02$, $p = .047$. The analysis of the simple effects showed that the reminder and the no-reminder group did not differ in source memory for Set 1 ($F < 1$). However, the no-reminder group correctly remembered the source for Set 2 objects significantly more often than the reminder group, $F(1, 18) = 4.74$, $MSE = 7.69$, $p = .043$. In the reminder group the source was better remembered for Set 1 than for Set 2 objects, $F(1, 18) = 17.99$, $MSE = 4.01$, $p < .01$. The number of objects for which the source was correctly remembered did not differ for Set 1 and 2 objects in the no-reminder group, $F(1, 18) = 1.51$, $MSE = 4.01$, $p = .235$.

In a second analysis, we looked at the mean number of objects for which the source was incorrectly remembered in a 2×2 mixed ANOVA with group (reminder vs no reminder) and set (1 or 2) as the independent variables. The main effects of set, $F(1, 18) = 10.21$, $MSE = 3.92$, $p < .01$, group $F(1, 18) = 10.29$, $MSE = 5.14$, $p < .01$, and the interaction between group and set were significant, $F(1, 18) = 5.75$, $MSE = 3.92$, $p = .03$. The analysis of the simple effects showed that the reminder and the no-reminder group did not differ

TABLE 1
Recognition performance in Experiments 1 and 2

	Set 1		*Set 2*	
	Hits	*False alarms*	*Hits*	*False alarms*
Experiment 1				
Reminder	98.00 (3.50)	3.50 (5.30)	96.50 (5.16)	2.00 (5.30)
No reminder	94.00 (5.16)	4.50 (8.32)	91.00 (13.29)	0
Experiment 2				
Reminder	90.00 (16.50)	2.50 (6.35)	96.00 (4.60)	2.50 (3.54)

Mean percentages of hits and false alarms for Set 1 and Set 2 objects in the Reminder and No-Reminder groups (standard deviations in parentheses).

in the number of source memory errors for Set 1, $F(1, 18) = 1.09$, $MSE = 2.94$, $p = .311$. However, for Set 2, the no-reminder group made significantly fewer source errors than the reminder group, $F(1, 18) = 11.81$, $MSE = 6.11$, $p < .01$. Furthermore, the reminder group made more source errors when remembering the source of Set 2 than Set 1 objects, $F(1, 18) = 15.64$, $MSE = 3.92$, $p < .01$, whereas in the no-reminder group source errors did not differ for Set 1 and 2 ($F < 1$).

We also compared the mean confidence ratings for the different source categories for objects labelled as ‘‘old’’ (i.e., confidence ratings for Set 1 and 2 objects whose source was correctly remembered, and for Set 1 objects that were falsely attributed to Set 2, and for Set 2 objects that were falsely attributed to Set 1). Because of the large number of missing values in the no-reminder group due to empty categories (6 out of 10 participants did not make one of the two possible source mistakes), we only statistically analysed the confidence ratings for the reminder group in which all participants made source misattributions for Set 2 objects, and 3 participants were excluded from the analysis because they did not make source mistakes for Set 1 objects. The mean confidence ratings for objects labelled old in the reminder group are depicted in Table 2. A 2 (Set 1 vs 2 objects) × 2 (source attribution: correct vs incorrect) repeated-measures ANOVA revealed only an interaction between the two factors, $F(1, 6) = 10.59$, $MSE = .118$, $p = .02$; all other effects $F \leq 3.22$, $p \geq .11$. An analysis of the simple main effects showed that for Set 1 but not for Set 2 objects that were labelled old, confidence ratings were significantly lower for incorrectly than for correctly remembered sources, $F(1, 6) = 11.58$, $MSE = .16$, $p = .01$, and $F < 1$ for Set 2 objects. Additionally, participants were significantly more confident in the source misattribution for Set 2 than Set 1 objects, $F(1, 6) = 8.82$, $MSE = .12$, $p = .03$, but there was only a statistical trend towards being more confident about correctly remembered sources for Set 1 in comparison to Set 2 objects, $F(1, 6) = 4.67$, $MSE = .06$, $p = .07$.

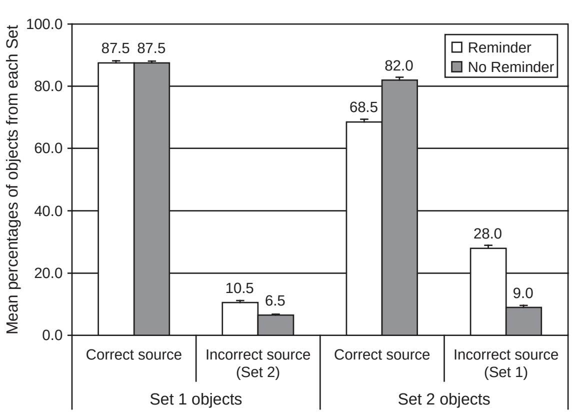

Figure 1. Experiment 1: Mean percentages of objects from Set 1 and Set 2 for which the sources were correctly or incorrectly identified in the reminder and no-reminder groups (error bars represent standard errors of the means).

TABLE 2
Mean confidence ratings

	Set 1 objects	*Set 2 objects*
Correct source attribution	4.42 (.34)	4.10 (.58)
Source misattribution	3.67 (.79)	4.19 (.34)

Mean confidence ratings for correctly and incorrectly attributed sources for objects labelled old in the reminder group (standard deviations in parentheses).

Discussion

The main result of Experiment 1 is that the memory-updating effect, i.e., intrusions from Set 2 into Set 1 but not from Set 1 into Set 2, was replicated in a source-monitoring paradigm. As in our previous studies using a recall paradigm, the updating was contingent upon a reminder: only participants who met the same experimenter in the same location as during Session 1, and answered a reminder question before learning Set 2, later claimed that a subset of the Set 2 objects were part of Set 1. Interestingly, they were as confident in the remembered source for correctly identified Set 2 objects as for Set 2 objects that they falsely attributed to Set 1. In contrast, for Set 1 objects, participants were less confident when they ascribed these incorrectly to Set 2 in comparison to ascribing them correctly to Set 1. This finding rules out the possibility that participants monitored their own confidence levels and attributed low-confidence items (from either set) to the older set (Set 1), which might have explained why in this paradigm we observe intrusions of Set 2 items into Set 1. In fact, those few items recognised with low confidence were instead attributed to the more recent Set 2. Overall our findings further strengthen the interpretation that the reminder reactivated the memory for Set 1 such that newly presented items could be incorporated.

What discriminates Set 1 from Set 2 memory? According to Johnson et al. (1993), source memory is affected by three factors: (1) the type and amount of source characteristics included in the activated memory records, (2) how unique these characteristics are for given sources, and (3) the criteria used for source decisions at test. While participants in both the reminder and no-reminder groups were treated similarly at test, there were differences during encoding between both groups. Specifically, there was a larger overlap of contextual cues between Set 1 and Set 2 memory for the reminder group: they learned both sets in the same room with the same experimenter. Additionally, they were asked to describe the encoding procedure with which they had learned Set 1 before learning Set 2 (in answer to the reminder question). In contrast, the no-reminder group learned Set 2 in a different room with a different experimenter, and no reminder question was asked. Both groups learned Set 2 with a slightly different encoding procedure. Thus both groups could have used the encoding procedure and the temporal context as source cues (e.g., participants could base their source judgements on the perceived age of the memory).[2] No-reminder participants, on the other hand, could have used the experimenter and the spatial context to keep their memories of the two sets separate. Therefore the reminder group might have been at a disadvantage in remembering the source correctly. However, the factors leading to the greater rate of intrusions in this group should have affected overall source discrimination, i.e., both sets. Instead, we observed source memory difficulties only for Set 2.

This is not to say that our finding does *not* reflect a source discrimination problem of some kind, because reminded participants obviously had difficulty remembering the source of Set 2 objects correctly. However, this source discrimination problem is highly specific in that it only occurs in the reminder group and is unidirectional, only affecting Set 2. We suspect that the underlying mechanism for this source discrimination problem in the reminder group is the reactivation of Set 1 memory during Session 2, which allows for the modification of Set 1 memory. This explanation is in agreement with current models of reconsolidation (e.g., Nader, 2003).

Alternatively, one could argue that our study design caused asymmetries in source errors. Previous studies have demonstrated that a variety of factors can cause such asymmetries. For instance, Durso and Johnson (1980) showed that certain encoding tasks cause words to be more often falsely recognised as having been encoded as pictures than vice versa, whereas other encoding tasks do not result in such an asymmetry. Other studies have revealed that test format (Marsh & Hicks, 1998), wishful thinking (Gordon, Franklin, & Beck, 2005), and vividness of visual imagery (Dobson & Markham, 1993; Eberman & McKelvie, 2002) can also cause biases in source misattributions.

Could some such factor have caused the asymmetrical error pattern in the reminder group

[2] Studies on list discrimination have shown that participants can use temporal information to differentiate between lists of items (e.g., Bastin & Van der Linden, 2005; Hintzman, Block, & Summers, 1973; Underwood & Malmi, 1978). In most studies the time delay between list presentations was less than 30 minutes. Our study is different in that it uses a delay of 48 hours, which should make it easier to differentiate the two presented sets, because additional features such as mood or other events in which the learning experiences are embedded can be expected to be more different when encoding takes place on different days.

in our study? There were two key differences between Set 1 and Set 2 learning: (1) Learning took place on two different days, and hence Set 2 was learned more recently than Set 1; and (2) Set 1 and 2 objects were presented differently. With regard to the first difference, the temporal asymmetry might have caused participants to expect to correctly remember the source of the more recently encoded (Set 2) objects. Hence, if source uncertainty occurred during test, participants by default might have assumed the object belonged to Set 1 (cf. Johnson, Raye, Foley, & Foley, 1981 for a related effect, the "it had to be you" bias). Such a bias should also be reflected in the source misattribution of false alarms: new objects that are falsely recognised should be attributed to Set 1 more often than to Set 2. Unfortunately, the false alarm rates in Experiment 1 were at floor levels, so the attributed sources could not be analysed. However, the confidence rating data speak against this uncertainty interpretation. For Set 2 objects, participants in the reminder group were as confident about correct source attributions as they were about misattributed sources. Additionally, those confidence ratings for Set 2 objects also did not differ from the confidence with which Set 1 items were correctly identified as being from Set 1. However, they were less confident about misattributed Set 1 objects.

Regarding the encoding procedure, the blue basket was differently emphasised across the two sessions in the reminder group, thus creating a contextual asymmetry. Set 1 but not Set 2 was learned using the blue basket. Before learning Set 2, the blue basket was briefly shown, and participants described what was done with it during Session 1. This could have resulted in Set 2 objects being loosely associated with the blue basket, which in turn could have caused some Set 2 objects to be attributed to Set 1, resulting in the observed source error asymmetry (Set 2 associated with Set 1 but not vice versa). If this was the case, then a reversal of procedures—i.e., only a brief mentioning of the blue basket at the end of session 1, and the use of the blue basket for encoding of Set 2—should cause a reversal of the asymmetrical source error effect (i.e., attributing Set 1 objects to Set 2). In contrast, the reconsolidation hypothesis would predict a replication of Experiment 1, because the order of events remains unchanged: reactivation of Set 1 memory in Session 2 renders it malleable, such that Set 2 objects are implanted into memory for Set 1. The effect of a reversal of encoding procedures was tested in Experiment 2.

EXPERIMENT 2

Method

Participants and materials. A total of 10 undergraduate students from the University of Arizona participated in the experiment. They received course credit for participation. The exact same materials as in Experiment 1 were used.

Procedure. The procedure was similar to the one employed in Experiment 1 with one critical difference: the encoding procedures were reversed.

In Session 1, Set 1 objects were all at once placed on a table in front of the participant with the task of naming all objects in a self-chosen order and an additional 30 seconds encoding time. Then the objects were removed, and the participants were asked to recall as many objects as possible. We used the same learning criterion as in Experiment 1; i.e., if participants recalled fewer than 17 objects the procedure was repeated. This continued until at least 17 objects were recalled or for a maximum of four learning trials. At the end of Session 1 the blue basket was shown, and participants were told that during the next session they would learn a different set of objects that would be sorted into this basket.

In Session 2 the participants were asked a reminder question ("Can you describe what we did on Monday?"), and then encoded the Set 2 objects by using the blue-basket procedure. The objects were taken out one by one from a bag in a random order and placed into the blue basket. The participants' task was to name each object. After the presentation, participants were asked to recall as many objects as possible, and the same learning criterion as in Session 1 was used. Session 3 was the same as in Experiment 1.

Results

As in Experiment 1, recognition memory was excellent (see Table 1). Because Hit and Correct Rejection rates were at ceiling, and Miss and False Alarm rates were at floor levels, we did not further analyse these scores.

The results of the source memory task are depicted in Figure 2. Source memory was analysed in two separate analyses. The mean number of objects for which the source was correctly remembered was analysed with a paired-samples *t*-test with set as the repeated variable. Significantly,

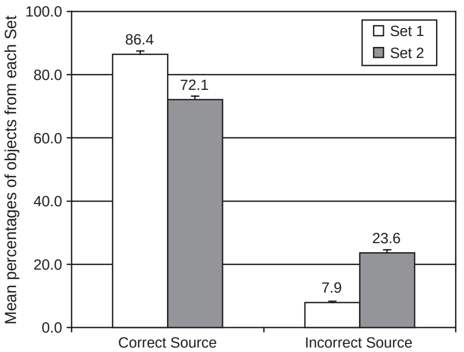

Figure 2. Experiment 2: Mean percentages of objects from Set 1 and Set 2 for which the sources were correctly or incorrectly identified (error bars represent standard errors of the means).

more correct source judgements were made for Set 1 than for Set 2 objects, $t(9) = 2.23, p = .05$. Second, we analysed source misattributions with a paired-samples t-test with set as the repeated variable. Set 2 objects were significantly more often attributed to Set 1 than Set 1 objects to Set 2, $t(9) = 3.55$, $p < .01$.

Confidence ratings were not further analysed, because 6 of the 10 subjects did not misattribute Set 1 objects to Set 2, leaving too few observations to justify a statistical analysis.

Discussion

In Experiment 2 we asked whether a reversal of encoding procedures (the basket was only briefly mentioned at the end of Session 1, but extensively used to encode Set 2 in Session 2) causes a reversal of the asymmetric pattern of source misattributions found in Experiment 1. Specifically, if the reminder question that included the blue basket in Experiment 1 created a bias towards associating Set 2 objects with the blue basket, then a reversal of encoding procedures and a brief mentioning of the blue basket at the end of Session 1 should result in some of the Set 1 objects being linked to the blue basket, which could cause Set 1 objects to be misattributed to Set 2 (the opposite of what we found in Experiment 1). The results of Experiment 2 clearly speak against this hypothesis, and instead strengthen the memory-updating interpretation of our results. Because the same course of events unfolded in Experiment 1 and 2 (Set 1 was learned 48 hours before Set 2, and participants were reminded of the first learning episode before encoding Set 2), one can assume that reminding participants causes memory for Set 1 to be reactivated such that Set 2 objects can be incorporated into the old memory.

GENERAL DISCUSSION

The present study replicates our previous finding of episodic memory updating (Hupbach et al., 2007, 2008) in a recognition/source memory paradigm. Contingent upon a reminder, participants misattributed newly encoded objects to the reactivated set. In contrast, participants rarely misattributed old objects to the new set (Experiment 1). The difference in procedures with which the two sets were encoded cannot explain this source misattribution asymmetry, because a reversal of procedures did not change the results (Experiment 2).

Because our paradigm shares many characteristics with the misinformation paradigm, it is interesting to compare our findings with the studies looking at the contribution of source misattributions to the misinformation effect. Interestingly, most of those studies only look at one source error, the frequency with which misleading post-event details are misattributed to the original event. The opposite, the frequency with which details from the original event are misattributed to the post-event questionnaire or narrative is often not reported. There are some exceptions (e.g., Hekkanen & McEvoy, 2002; Lane, Mather, Villa, & Morita, 2001; Mitchell, Johnson, & Mather, 2003). In addition to the common finding of misattributing some of the details of the post-event information to the original event, those studies show that very few details from the original event are falsely attributed to the post-event narrative or questionnaire. Thus, comparable to our study, the source misattribution occurs for items that were introduced *after* the original event, and not, or to a much lesser degree, for items that were part of the original event. Similarly, in a study on proactive and retroactive effects of negative suggestions, Brown, Brown, Mosbacher, and Dryden (2006) did not find a false information effect when the incorrect information preceded the correct information but the effect was apparent when the incorrect information was presented afterwards. However, a reversed suggestibility effect was demonstrated by Lindsay and Johnson (1989b). Before viewing a single slide for 20 seconds depicting an office scene, participants read a narrative description of that scene. For half of the participants the narrative contained the objects that fit the office scheme but were not actually presented in the slide. Misled participants claimed that about 44% of the suggested items were part of the slide. However, even non-misled participants falsely claimed that about 25% of those items stemmed from the slide, although those objects were not even mentioned in their version of narrative. This suggests that the observed intrusion effect reflects the activation of a general office schema.

Studies demonstrating unidirectional updating suggest that there is something special about the ''original'' episode, and we think that it would be fruitful to look at those findings from a reconsolidation perspective. In the misinformation paradigm, participants are always ''reminded'' of the original event when the misinformation is presented. The misinformation narrative or questionnaire is directly related to the original event, because it asks about the original episode. Hence, one can assume that the memory for the original event is reactivated by the post-event information, thus opening it up to modification. That we see fewer intrusions from the original event into the post-event narrative or questionnaire suggests that only the reactivated memory is modified (but see Lindsay & Johnson, 1989b, above). In order to further evaluate the value of the reconsolidation account as an explanation for the misinformation effect, future studies need to address whether post-event information that does *not* contain an apparent reminder leaves the original memory unaffected, as would be expected by the reconsolidation account. However, one has to be cautious about this interpretation because, in contrast to our study, the witnessed and suggested items in the misinformation studies are usually not matched on dimensions of presentation mode (visual vs verbal), length of exposure, etc. Those dimensions can cause asymmetry in source misattributions (see discussion of Experiment 1). In order to differentiate between a source asymmetry and the reconsolidation explanation, future studies need to match the witnessed and suggested items as closely as possible.

Taken together, our study shows that the modification of episodic memory content that occurs contingent upon its reactivation and presentation of additional information cannot be attributed to a symmetrical source discrimination problem. When asked about the source of their memories, participants claim that some of the objects presented after the reminder were part of the original event. This in fact reflects updating of the original memory and replicates our previous findings (Hupbach et al. 2007, 2008). Importantly, participants do not misattribute the source of objects presented during the original event to the post-reminder episode.

First published online 26 May 2009

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