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Neutral mood induction during reconsolidation reduces accuracy, but not vividness and anxiety of emotional episodic memories

Guanyu Liu*, Richard J. McNally

Harvard University, Department of Psychology, 33 Kirkland Street, Cambridge, MA 02138, USA

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ABSTRACT

Background and objectives: Consolidated memories become labile upon reactivation and as a result have to go through reconsolidation to become re-stabilized. This property of memory may potentially be used to reduce the impact of highly negative episodic memories. Because detailed and vivid negative memories are mediated by high arousal, if arousal is lessened during reconsolidation, memory accuracy and vividness should diminish. In this study, we examined this hypothesis.
Methods: Participants ($N = 72$) viewed a stressful, suspenseful video on Day 1 to develop negative episodic memories. Then, 24–29 h later, they saw a brief reminder of the stressful video (or not), and then viewed a neutral, calming (or positive) video. Another 24–29 h later, participants were tested on the accuracy, vividness, and anxiety associated with their memory of the stressful video on Day 1.
Results: Participants who watched the reminder and then the neutral video showed reduced memory accuracy compared to participants in the other groups. Despite the reduction in memory accuracy, their memory vividness and anxiety associated with the stressful video did not decrease.
Limitations: The use of undergraduates prevents generalizations to clinical populations. Also, the study did not test long-term memories that were more than 2 days old.
Conclusions: Neutral mood induction during reconsolidation reduces the accuracy of highly negative episodic memories.

When consolidated memories are reactivated, they become labile, thereby requiring reconsolidation to become restabilized (Dudai, 2004; Sara, 2000). During reconsolidation, memories become subject to modification (e.g., Nader, Schafe, & LeDoux, 2000). Such malleability represents an opportunity to reduce the stressful quality of negative memories (Kindt & Soeter, 2013; Schiller, Kanen, LeDoux, Monfils, & Phelps, 2013).

Stressful experiences are memorable because they are usually arousing (Kensinger & Schacter, 2008; McNally, 2003). Arousal stimulates the release of stress hormones that strengthen memories (McGaugh, 2000). Although the memory-enhancing effect of arousal is generally adaptive, it can lead to pathological memory expressions after trauma (e.g., flashbacks or intrusive memories; McNally, 2003).

Because arousal mediates the accuracy and vividness of negative memories, lowering arousal during reconsolidation may diminish their subsequent accuracy and vividness. For example, Schwabe, Nader, and Pruessner (2013) found that administering propranolol during reconsolidation reduced the accuracy and vividness of negative memories. Similarly, Kroes et al. (2014) found that administering electroconvulsive therapy (ECT) on depressive patients during reconsolidation reduced the accuracy

* Corresponding author. Department of Psychological and Brain Sciences, University of Massachusetts Amherst, 135 Hicks Way, Amherst, MA 01003, USA.
E-mail address: gliu@psych.umass.edu (G. Liu).

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of negative memories.[1] The clinical implications of such procedures are limited as both require medical supervision and both have side effects.

Accordingly, in this experiment, we endeavored to replicate the findings of these recent studies, but without relying on propranolol or ECT as the agents of reconsolidation disruption. In addition, we explored whether anxiety associated with negative episodic memories could be reduced. The reason for this exploration is twofold: First, anxiety is a frequent response to recalling negative episodic memories (McNally, 2003). Second, anxiety reduction has not been tested in the reconsolidation of emotional episodic memories despite having been tested in the reconsolidation of conditioned fear memory (Agren, 2014).

We tested whether exposing participants to a neutral, calming video during reconsolidation of negative episodic memories would attenuate the accuracy, vividness, and anxiogenic qualities of such memories. We used a neutral video because neutral, non-sensational video can reduce arousal (Zillmann & Johnson, 1973).

The experiment was conducted over three days. On Day 1, all participants viewed a stressful video comprising scenes from the suspense film *The Shining* (Kubrick & Kubrick, 1980), shown in a darkened laboratory testing room. Immediately thereafter, they recalled the video and took a quiz about it. On Day 2, participants were randomized to one of four groups (i.e., reminder/neutral, no reminder/neutral, reminder/positive, no reminder/positive). In the same darkened room, the reminder/neutral group viewed a brief segment from Day 1's video to reactivate their memory prior to watching a calming, neutral clip from the documentary *Baraka* (Magidson & Fricke, 1993). The reminder/positive group, in the same darkened room, viewed the same reminder prior to watching an amusing clip from *America's Funniest Home Videos* (Di Bona, 1989). In a different, brightly lit testing room, the no reminder/neutral and the no reminder/positive groups watched only the neutral and positive videos, respectively. On Day 3, all participants underwent tests for memory accuracy, vividness, and anxiety associated with the stressful video on Day 1. We included the positive video as a control condition to rule out the possibility that it was the relatively positive valence in the neutral video that caused the reduction in the dependent variables.

We predicted that participants exposed to the neutral video following reactivation of the memory of the stressful video would exhibit decrements in memory accuracy, vividness, and anxiety for the stressful video on Day 3, relative to the other groups.

1. Method

1.1. Participants

Participants were recruited from the Harvard University Psychology Study Pool. Eligible participants were between 18 and 65 years of age, fluent in English, and free of psychiatric or neurological disorders. Eighty-eight eligible participants were initially enrolled, but 16 had to be excluded prior to data analyses. Seven failed to follow instructions; four terminated participation because they found the stressful video too scary; and five failed to return for either session 2 or 3.

The final group consisted of 72 participants (44 women) aged 18–40 (M = 20.18, SD = 3.49). Their ethnic backgrounds were Caucasian (47.2%), Asian (31.9%), Hispanic (9.7%), Multi-racial (5.6%), African-American (4.2%), and Arabic (1.4%). They received course credits for their participation.

A post hoc power analysis indicated that the study had 80% power to detect an interaction effect of 0.33 (Faul, Erdelder, Buchner, & Lang, 2009).

1.2. Design

The experiment was a 2 × 2 between-subjects design with main factors of Reactivation (reminder, no reminder) and Video (neutral, positive). The dependent variables were three self-report measures: memory accuracy, memory vividness, and memory anxiety. The study was approved by the Harvard Committee on the Use of Human Subjects.

1.3. Materials

Apparatus. The experiment was programmed in OpenSesame, a free, cross-platform experiment builder (Mathot, Schreij, & Theeuwes, 2012), and was administered on an HP Pavillion dv6 laptop computer.

Videos. Three video clips having negative, positive, and neutral valence were used. Prior to launching the study, six pilot participants rated the emotionality of the videos. They rated each video on two 1–7 Likert scales in which 1 denoted highly negative (valence)/highly calming (arousal), 4 denoted neutral (both valence and arousal), and 7 denoted highly positive (valence)/highly arousing (arousal).

The negative video clip lasted 20 min and 22 s. It comprised four scenes from *The Shining* (Kubrick & Kubrick, 1980), a suspense film confirmed as strongly fear-evocative (Gross & Levenson, 1995). During piloting, its valence and arousal ratings and standard deviations were 1.83 ± 0.98 and 6.5 ± 0.55.

The positive video clip lasted 20 min and 25 s. It comprised amusing episodes from the television program *America's Funniest Home Videos* (Di Bona, 1989). During piloting, its valence and arousal ratings and standard deviations were 5.83 ± 0.75 and 4.83 ± 0.98.

The neutral video clip lasted 20 min and 30 s. It comprised scenes of people and landscapes from the documentary, *Baraka* (Magidson & Fricke, 1993). During piloting, its valence and arousal ratings and standard deviations were 4 ± 0 and 1.75 ± 0.5, (N = 4).

An excerpt from the stressful video clip, lasting 1 min and 30 s, was used as a reminder to reactivate participants' memory of the stressful video. Moreover, it was edited to create an abrupt,

[1] Research on episodic memory reconsolidation has examined neutral episodic memory (Hupbach, Gomez, Hardt, & Nadel, 2007), autobiographical memory (Schwabe & Wolf, 2009), negative episodic memory (Schwabe et al., 2013), and trauma memory (Kredlow & Otto, 2015). Hupbach et al. (2007) were the first to report a reconsolidation update effect of episodic memory. Participants learned a list of unrelated objects on Day 1. On Day 2, they either received a reminder or not and then learned a second list of objects. Their memory for the first list was tested on Day 3. Results showed that participants who received the reminder before learning the 2nd list incorrectly mixed more objects from the 2nd list into the 1st list, thereby demonstrating a reconsolidation update. Schwabe and Wolf (2009) investigated the reconsolidation of autobiographical memory. They had participants first recall positive, neutral, and negative autobiographical events and then receive a neutral interference task (a short story). One week later, participants' memories of these events were tested. Results showed that memory (number of details remembered) decreased only for the neutral events; it did not decrease for the positive or negative events. Schwabe et al. (2013) used the beta-adrenergic blocker to examine the reconsolidation of negative episodic memory. Participants encoded 25 negative and 25 neutral photos on Day 1. On Day 2, depending on the condition, participants received either propranolol or placebo, and they received either a reminder or no reminder. Participants' memory for the photos was tested on Day 3. Results showed that participants who received propranolol and the reminder remembered fewer photos than did participants in the other 3 conditions. For the photos they remembered, they also reported less vividness than the other 3 groups. Kredlow and Otto (2015) was the first to report on a reconsolidation update effect on trauma memory. In the experiment, participants first recalled (negative) memories of the Boston Marathon bombings before receiving either a positive, neutral, or negative interference in the form of a short story. Results showed that participants who received the negative interference showed the greatest reduction in the number of details recalled.

suspenseful ending, thus producing a mismatch between what was expected and what was seen. This mismatch reminder structure triggers reconsolidation because it disrupts expectation (Coccoz, Maldonado, & Delorenzi, 2011). Furthermore, for the two reactivation groups, a 3-min interval ensued after the reminder, before a new video was presented to allow time for amygdala-mediated, consolidated fear memory to destabilize after its reactivation (Monfils, Cowansage, Klann, & LeDoux, 2009).

1.4. Experimental rooms and lighting

To facilitate memory reactivation for the reactivation groups and to prevent reactivation by identical physical context for the no-reactivation groups (Hupbach, Hardt, Gomez, & Nadel, 2008), we used two laboratory testing rooms. On Day 1, participants watched the stressful video clip in the darkened first room, and this darkened room was also used on Day 2 for participants in the reactivation conditions. In contrast, another brightly-lit room was used on Day 2 for participants assigned to the no-reactivation conditions and for all groups on Day 3 and for the post experimental debriefing.

1.5. Memory quiz

Participants received the first memory quiz on Day 1 after they watched the stressful video, thereby ensuring that they encoded it. The first quiz contained 9 multiple-choice questions, mainly concerning its factual details (e.g., "What does the boy use to write on the door?").

Participants received the second memory quiz on Day 3 to assess the effect of reconsolidation on memory accuracy. It consisted of 20 multiple-choice questions concerning details of the stressful video (e.g., "What does the man say after he breaks the bathroom door?").

1.6. Procedure

The experiment was conducted on three consecutive days, 24–29 h apart, to allow for memory consolidation and reconsolidation (Fig. 1).

1.6.1. Day 1 — Baseline and video encoding

On Day 1, participants provided written informed consent before completing a demographic questionnaire asking about their age, gender, and ethnicity. They were then asked to turn to the screen of a computer, at which point the experimenter switched off the lights and exited the room.

Participants saw the following instructions on the computer screen: "In today's experiment, you will first rate your mood and then watch a movie. After the movie, you will complete some questionnaires. Please click NEXT when you are ready to begin." Participants were then presented with the instructions: "Please rate how you feel at this moment. Indicate your rating by clicking on 1 of the 7 boxes below. 1 = very calm, 7 = very anxious. When you are done, press NEXT to proceed." After the rating, participants viewed the stressful video on the computer. Immediately thereafter, they were presented the following instructions: "Recall the movie you just watched. Bring it to mind as if you were watching it right now. In a moment, the screen will go blank for 30 s. While the screen is blank, please recall the movie as best as you can."

After a 30-s pause, participants were asked to rate the vividness of their memory of the video: "When recalling the movie, how vivid was your memory? Indicate your rating by clicking on 1 of the 7 boxes below: 1 = not vivid at all, 7 = very vivid." After the vividness rating, they were asked to rate the anxiety prompted by the memory: "When recalling the movie, how anxious did the memory of the movie make you feel? Indicate your rating by clicking on 1 of the 7 boxes below: 1 = not anxious at all, 7 = very anxious." Participants were then asked: "Have you ever seen this movie before the experiment? 0 = no, 1 = yes."

After indicating their prior exposure to the stressful video clip, participants were prompted to rate its valence and arousal. They were first instructed: "Please rate the valence of the movie, i.e., how positive or negative did the movie make you feel? 1 = highly negative, 4 = neutral, 7 = highly positive" and thereafter: "Please rate the arousal of the movie, i.e., how aroused did the movie make you feel? 1 = highly calming, 4 = neutral (neither calming nor arousing), 7 = highly arousing."

After the ratings, participants were given the first quiz. They were then thanked and reminded of the session the next day.

1.6.2. Day 2 — Memory reactivation and mood induction

After Day 1's procedure, participants were randomly assigned to one of four experimental groups: reminder/neutral, reminder/positive, no reminder/neutral, no reminder/positive. The group assignments determined whether participants would first watch a reminder of the stressful video as well as whether they would then watch a neutral or positive video.

Reminder/Neutral group. After seated in lab room 1 (same room as Day 1), participants were presented with the following instructions: "Today you will first watch an excerpt from yesterday's movie. Then you will watch a new movie and complete a set of questionnaires. Please click NEXT when you are ready to begin." Participants then viewed the reminder. Thereafter, they were instructed: "The movie excerpt has finished. Please relax for the next 3 min. The new movie will begin at that time." Then a white blank screen appeared and lasted for 3 min, after which the neutral video was automatically played on the computer. After viewing the video, participants were first asked to rate its valence: "Please rate the valence of the movie, i.e., how positive or negative did the movie make you feel? 1 = highly negative, 4 = neutral, 7 = highly positive. Indicate your rating by clicking on 1 of the 7 boxes below." Immediately thereafter, they rated how arousing the video was: "Please rate the arousal of the movie, i.e., how aroused did the movie make you feel? 1 = highly calming, 4 = neutral (neither calming nor arousing), 7 = highly arousing. Indicate your rating by clicking on 1 of the 7 boxes below." They were then asked, "Approximately how many hours of sleep did you get last night? Indicate your rating by clicking on 1 of the 7 boxes below." The boxes were labeled, "less than 4," "4," "5," "6," "7," "8," and "more than 8." Participants were then thanked and reminded of the third session the following day.

Reminder/Positive group. The procedure was identical to the procedure for the *reminder/neutral group*, except that participants in this group watched the positive video instead of the neutral one.

No Reminder/Neutral group. Participants in this group completed Day 2's procedure in the brightly-lit lab room 2 to prevent spontaneous memory reactivation by context. After sitting down at the computer, they were presented with the following instructions: "Today you will first watch a movie and then complete a set of questionnaires. Please click NEXT when you are ready to begin." Participants then proceeded to watch the neutral video. The ratings of arousal and valence, the question about hours of sleep, and the reminder about the next session occurred as described above.

No Reminder/Positive group. The procedure was identical to the procedure for the *no reminder/neutral group*, except that participants in this group watched the positive video instead of the neutral one.

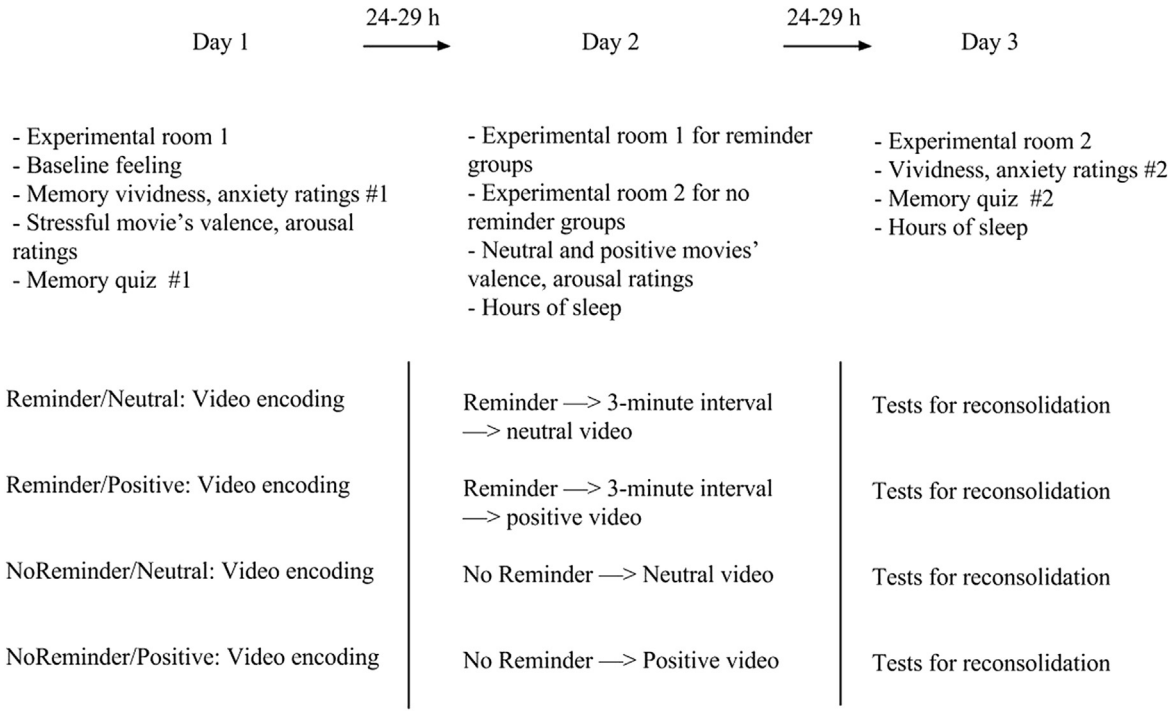

Fig. 1. Experimental procedure.

1.6.3. Day 3 — Testing

In room 2, all participants received the following instructions: "In today's experiment, you will complete some questionnaires. Please click NEXT when you are ready to begin." Thereafter, they were instructed: "Recall the stressful movie you watched on the first day of this experiment. Bring it to mind as if you were watching it right now. In a moment, the screen will go blank for 30 s. While the screen is blank, please recall the movie as best as you can." A white blank screen then appeared for 30 s, after which the following instructions appeared: "When recalling the stressful movie, how vivid was your memory? Indicate your rating by clicking on 1 of the 7 boxes below. 1 = not vivid at all, 7 = very vivid." Then, participants were presented with the next set of instructions: "When recalling the stressful movie, how anxious did the memory of the movie make you feel? Indicate your rating by clicking on 1 of the 7 boxes below. 1 = not anxious at all, 7 = very anxious." After the rating, participants were asked to indicate the number of hours of sleep they had the previous night. Next, participants were given the second memory quiz, which consisted of 20 multiple-choice questions. After the quiz, participants were debriefed about the experiment before departing.

1.7. Statistical analysis

Because recording of self-reported hours of sleep began with the fourth participant, data were missing for the first 3 participants. We used the expectation maximization algorithm in SPSS to predict and repopulate the missing values. Also, one participant did not report her anxiety rating of the stressful video on Day 1, but retrospectively reported the rating on Day 2. In addition, we removed data points outside of 3 standard deviations from the mean on any of the dependent measures. This resulted in the elimination of 1 data point in day 1 accuracy scores, 3 data points in age, and 1 data point in the arousal ratings of the stressful video.

1.7.1. Day 1 measures

We used one-way analyses of variance (ANOVAs) of group for the following variables: age, baseline feeling, memory accuracy, memory vividness, memory anxiety, and stressful video's valence and arousal ratings. We used chi-square tests to examine group differences in gender, ethnicity, and whether participants had seen the stressful video before the experiment.

1.7.2. Day 2 measures

To test between group differences in valence and arousal of both the neutral and positive videos, we conducted four independent-samples *t*-tests (i.e., reminder/neutral vs. no reminder/neutral in valence and arousal, and reminder/positive vs. no reminder/positive in valence and arousal), using the Bonferroni procedure to adjust the alpha level to $p < 0.0125$.

Also, to assess whether mood induction was successful on Day 2, we conducted four paired-samples *t*-tests to assess differences in valence and arousal ratings between the stressful video and the neutral video, as well as between the stressful video and the positive video, adjusting the alpha level to $p < 0.0125$.

Finally, we tested group differences in the number of hours of sleep via a one-way ANOVA with a main effect of group.

1.7.3. Day 3 measures

We used two-way ANOVAs to test for reconsolidation effects on memory accuracy, memory vividness, and memory anxiety with main effects of Reactivation (reminder, no reminder) and Video (neutral, positive). When significant interactions occurred, we conducted two simple main effect analyses of reactivation and of video, adjusting the alpha level to $p < 0.025$.

2. Results

Using the expectation maximization algorithm in SPSS, we repopulated the six missing values for hours of sleep after confirming that data were missing completely at random, $\chi^2 = 13.57$

($df = 8$, $p < 0.094$).

2.1. Day 1 measures

The groups did not differ significantly in gender, $\chi^2(3, N = 72) = 1.40$, $p = 0.71$, ethnicity, $\chi^2(15, N = 72) = 13.24$, $p = 0.58$, or age, $F(3, 65) = 1.30$, $p = 0.28$. They did not significantly differ in baseline feeling, $F(3, 68) = 0.67$, $p = 0.58$, $\eta^2 = 0.03$, memory accuracy, $F(3, 67) = 1.14$, $p = 0.34$, $\eta^2 = 0.05$, memory anxiety, $F(3, 68) = 0.41$, $p = 0.74$, $\eta^2 = 0.02$, and memory vividness, $F(3, 68) = 1.02$, $p = 0.39$, $\eta^2 = 0.04$.

They did not differ significantly in the proportion of people who had previously seen *The Shining*, $\chi^2(3, N = 72) = 4.54$, $p = 0.21$. Table 1 summarizes the measures.

Video ratings. After watching the stressful video, the groups did not differ in their ratings of valence, $F(3, 68) = 1.04$, $p = 0.38$, $\eta^2 = 0.04$, or arousal, $F(3, 67) = 2.06$, $p = 0.11$, $\eta^2 = 0.08$. Table 2 summarizes the video ratings.

2.2. Day 2 measures

The two groups that watched the neutral video did not differ significantly in their ratings of valence, $t(34) = 1.20$, $p = 0.24$, $d = 0.40$, or arousal, $t(34) = 1.70$, $p = 0.10$, $d = 0.57$. Similarly, the two groups that watched the positive video did not differ significantly in their ratings of valence, $t(34) = 0.20$, $p = 0.85$, $d = 0.07$, or arousal, $t(34) = 0.17$, $p = 0.91$, $d = 0.04$.

The 4 groups also did not differ significantly in hours of sleep for the preceding night, $F(3, 68) = 0.44$, $p = 0.73$, $\eta^2 = 0.02$.

Mood induction. Participants' ratings on the neutral and positive videos suggested that the mood induction was successful. The neutral video's mean valence and arousal ratings were 4.61 and 1.97, respectively. The positive video's mean valence and arousal ratings were 6.03 and 3.92, respectively.

Moreover, to assess whether these valence and arousal ratings were significantly different from those of the stressful video, we conducted 4 paired-samples *t*-tests (alpha adjusted to $p < 0.0125$). Results showed that participants in the neutral groups rated the neutral video as significantly more positive than the stressful video, $t(35) = 7.83$, $p < 0.001$, $d = 1.31$, and significantly less arousing than the stressful video, $t(35) = 14.93$, $p < 0.001$, $d = 2.49$. Similarly, participants in the positive groups rated the positive video as significantly more positive than the stressful video, $t(35) = 19.23$, $p < 0.001$, $d = 3.20$, and significantly less arousing than the stressful video, $t(35) = 7.03$, $p < 0.001$, $d = 1.17$. Table 3 and Table 4 summarize the results.

2.3. Day 3 measures

Memory accuracy. We hypothesized that participants who watched the reminder and then the neutral video would remember *fewer* details of the stressful video than would participants in the other groups. The results supported this hypothesis. There was a significant interaction between reactivation and video, $F(1, 68) = 7.32$ $p = 0.01$, $\eta^2_p = 0.10$ (Fig. 2). Therefore, we performed two simple main effects analyses, Bonferroni-adjusted to $p < 0.025$.

As indicated by a significant simple main effect of reactivation, $F(1, 68) = 10.68$, $p = 0.002$, $\eta^2_p = 0.14$, participants who viewed the reminder before watching the neutral video subsequently recalled fewer details from the stressful video than did participants who did not view the reminder before watching the neutral video (Fig. 2). However, the simple main effect of reactivation was nonsignificant for those who watched the positive video, $F(1, 68) = 0.31$, $p = 0.58$, $\eta^2_p = 0.01$.

The simple main effect of video was nonsignificant for participants who viewed the reminder, $F(1, 68) = 4.30$, $p = 0.04$, $\eta^2_p = 0.06$, or for participants who did not view the reminder, $F(1, 68) = 3.08$, $p = 0.08$, $\eta^2_p = 04$ (Fig. 2).

Given the significant simple main effect of reactivation, we conducted a pair-wise comparison for the reminder/neutral vs. no reminder/neutral groups. The mean memory accuracy scores were 0.77 ($SD = 0.09$) and 0.88 ($SD = 0.08$): Participants who watched the reminder recalled 11 percent *fewer* details of the stressful video than those who did not watch the reminder, $d = 1.35$, 95% CI (−0.18 to −0.04), $p = 0.002$.

Memory vividness. We hypothesized that participants who

Table 1
Means and standard deviations of Day 1 measures (incl. baseline feeling, age, memory accuracy, vividness, anxiety, and whether participants had seen the movie before).

Variable	Re + Neutral($n = 18$)		NoRe + Neutral ($n = 18$)		Re + Positive ($n = 18$)		NoRe + Positive ($n = 18$)	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Baseline feeling	2.50	1.20	3.06	1.11	2.83	1.20	2.83	1.25
Age	20.17	3.43	19.28	1.02	20.06	3.11	21.22	5.12
Memory accuracy	96%	8%	96%	8%	94%	8%	96%	7%
Memory vividness	5.39	0.61	5.67	0.77	5.89	0.90	5.78	1.22
Memory anxiety	4.56	1.29	4.17	2.36	4.17	1.20	4.67	1.78
	Yes	*No*	*Yes*	*No*	*Yes*	*No*	*Yes*	*No*
Seen before	1	17	5	13	6	12	5	13

Note. Baseline feel ratings were on the scale of 1–7, with 1 being very calm, 7 being very anxious. Memory vividness and anxiety ratings were on the scale of 1–7, with 1 being not at all vivid/not at all anxious, 7 being very vivid/very anxious.

Table 2
Means and standard deviations of the valence and arousal ratings of the stressful video (Day 1).

Variable	Re + Neutral ($n = 18$)		NoRe + Neutral ($n = 18$)		Re + Positive ($n = 18$)		NoRe + Positive ($n = 18$)	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Stressful video valence	2.39	1.09	2.61	1.29	2.28	0.89	2.00	0.91
Stressful video arousal	5.44	1.04	5.83	0.99	5.89	1.18	6.06	0.80

Note. Valence and arousal ratings were on the scale of 1–7, with 1 being the most negative (in valence)/most calming (in arousal), 7 being the most positive (in valence)/most arousing (in arousal).

Table 3
Contrasts of neutral video groups' valence and arousal ratings for the neutral video on Day 2 with their valence and arousal ratings for the stressful video on Day 1.

Variable	Neutral video groups		*t*(35)	*p*	95% CI		Cohen's *d*
	M	*SD*			*LL*	*UL*	
Neutral video valence	4.61	0.84	7.83	<0.001	1.56	2.66	1.31
Stressful video valence	2.5	1.18					
Neutral video arousal	1.97	1.11	−14.93	<0.001	−4.17	−3.17	2.49
Stressful video arousal	5.64	1.02					

Note. CI = confidence interval; *LL* = lower limit; *UL* = upper limit.

Table 4
Contrasts of positive video groups' valence and arousal ratings for the positive video on Day 2 with their valence and arousal ratings for the stressful video on Day 1.

Variable	Positive video groups		*t*(35)	*p*	95% CI		Cohen's *d*
	M	*SD*			*LL*	*UL*	
Positive video valence	6.03	0.84	19.23	<0.001	3.48	4.30	3.20
Stressful video valence	2.14	0.90					
Positive video arousal	3.92	1.42	−7.03	<0.001	−2.65	−1.46	1.17
Stressful video arousal	5.97	1.00					

Note. CI = confidence interval; *LL* = lower limit; *UL* = upper limit.

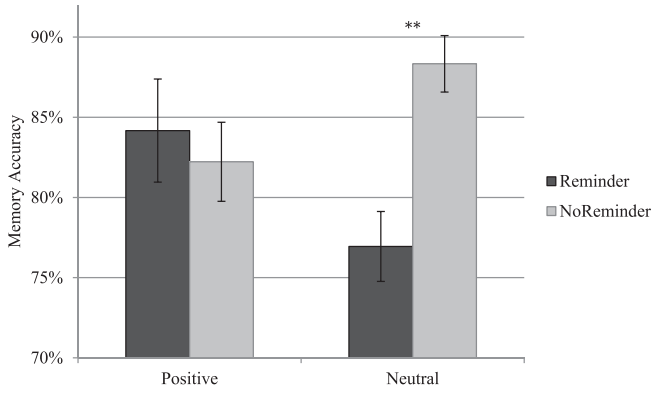

Fig. 2. Effects of Manipulation on Reconsolidation of Memory Accuracy. Note: Error bars represent the standard errors of the mean. **p < 0.01.

watched the reminder and then the neutral video would remember the stressful video less vividly than would participants in the other groups. The results did not support this hypothesis. There was no statistically significant interaction between reactivation and video, $F(1, 68) = 0.22$, $p = 0.64$, $\eta^2_p = 0.00$. There were also no main effects, *ps* > 0.28 (Fig. 3).

Memory anxiety. We hypothesized that participants who watched the reminder and then the neutral video would show lowered memory anxiety than would participants in the other groups. The results did not support this hypothesis. There was no statistically significant interaction between reactivation and video, $F(1, 68) = 0.11$, $p = 0.74$, $\eta^2_p < 0.01$. There were also no main effects, *ps* > 0.41 (Fig. 4).

Hours of sleep. There were no significant differences among the groups, $F(3, 68) = 1.31$, $p = 0.28$, $\eta^2 = 0.05$.

3. Discussion

We investigated whether memory accuracy, vividness, and anxiety could be reduced during reconsolidation via neutral mood induction.

Memory accuracy declined for participants who watched the reminder of the stressful video prior to the neutral, calming video. The result replicates findings from studies on the reconsolidation of emotional episodic memories that used β-blockers or electroconvulsive therapy (Kroes et al., 2014; Schwabe et al., 2013). The accuracy reduction is likely due to a reduction in arousal during reconsolidation. Arousal enhances memory encoding and leads to accurate memories (Kensinger & Schacter, 2008). Hence, lowering arousal should reduce its enhancing effect on memory accuracy for

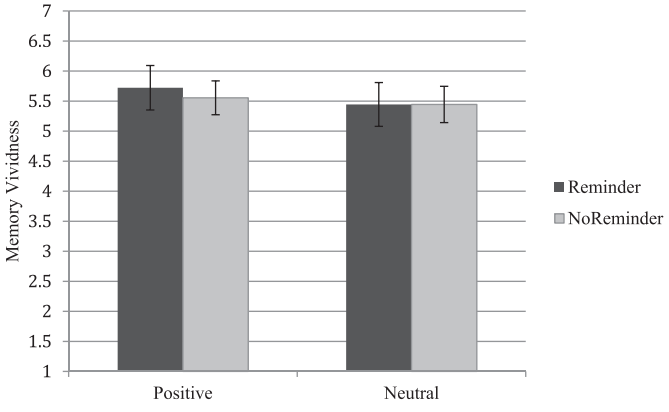

Fig. 3. Effects of Manipulation on Reconsolidation of Memory Vividness. Note: Error bars represent standard errors of the mean.

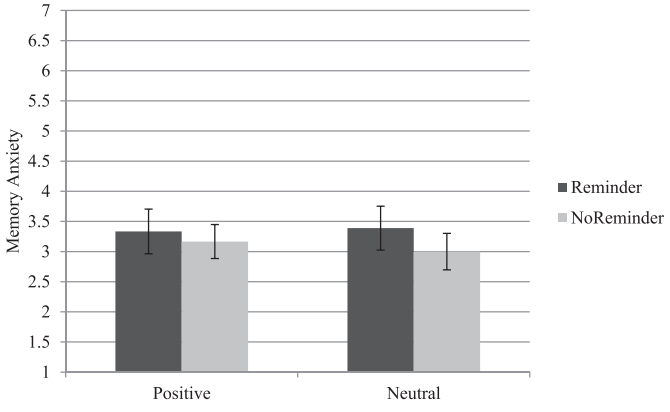

Fig. 4. Effects of Manipulation on Reconsolidation of Memory Anxiety. Note: Error bars represent standard errors of the mean.

details (Schwabe et al., 2013). The result is strong, especially considering that memory for movies is robust, accurate, and persists for months (Furman, Dorfman, Hasson, Davachi, & Dudai, 2007). Moreover, only the reminder/neutral group experienced the reconsolidation-associated attenuation of accuracy for the stressful video.

This result cannot be attributed to a retroactive interference effect whereby newly acquired video information impairs participants' ability to remember previously acquired stressful video information. If this were the case, we would expect the reactivation/positive video group to remember fewer details because the positive movie involved far more stimuli that would have markedly impaired recollection of the stressful video.[2]

However, memory vividness did not decline for participants who viewed the reminder prior to the calming video. This is inconsistent with Schwabe et al.'s (2013) on propranolol's effect on memory vividness during reconsolidation. The result is surprising because arousal typically drives vividness (McGaugh, 2000; Phelps, 2004), and if the arousal declined during reconsolidation, so should vividness.

There are several possible explanations. First, unlike propranolol, the calming video may have been insufficiently potent to dampen vividness during reconsolidation especially as its duration was only 20 min and its effects transient, whereas the effects of propranolol last for hours (Nies & Shand, 1975).

Second, it could be due to the way memory vividness was examined. It was examined by the question: “when recalling the movie, how vivid was your memory?” Although participants reported high vividness, the nature of the vividness was ambiguous. For example, it could be that they remembered specific perceptual or contextual details vividly, or it could be that they were biased to report high vividness because the experience was emotional, especially considering that emotional experiences lead to an inflated sense of vividness (Sharot, Delgado, & Phelps, 2004).

One way to correct this potential bias would be to use the “old”/”new,” “remember”/”know” procedure (Eldridge, Sarfatti, & Knowlton, 2002). In this procedure, participants are first asked to indicate whether they have previously encountered a stimulus. If they selected yes, they are then asked whether they can recall it with vivid contextual details (i.e., “remember”), or without any contextual details (i.e., “know”). Hence, the procedure allows for a more specific test of vividness. Also, the procedure does not ask participants to reflect on an experience as a whole (e.g., recall a stressful video), but asks participants to respond to specific stimuli within the experience. Hence, participants would be asked whether they recognized a given screenshot from the stressful video; if so, they would then be asked whether they could vividly recall it (i.e., “remember”) or merely remember that it happened (i.e., “know”).

In addition, we explored whether memory anxiety can be reduced during reconsolidation in participants who viewed the reminder of the stressful video and then the neutral video. We did not observe a reduction. We did, however, observe a significant reduction in participants' anxiety scores from Day 1 (4.39) to Day 3 (3.22), $F(1, 68) = 39.67$, $p < 0.001$, $\eta^2_p = 0.37$. This was likely attributable to a natural decline in anxiety over time.

The current study contributes to a growing body of literature concerning reconsolidation via behavioral manipulations. Though largely consistent with the results of this literature (see Agren, 2014 for a review), our results do not agree with some experiments. For example, Schwabe and Wolf (2009) found that neutral intervention, not positive or negative interventions, reduced neutral-content memory after its reactivation. Similarly, Kredlow and Otto (2015) reported that negative intervention, not positive or neutral interventions, reduced trauma memory after its reactivation. These results suggest that the valence of the interfering material is important for achieving reconsolidation interference (i.e., it has to match the valence of the original memory).

At first glance, these results seem to contradict our results that neutral intervention reduces memory accuracy for negative memory. However, we do not think they are incompatible. The likely reason for differing results in these studies is that they were testing different mechanisms. Schwabe and Wolf (2009) and Kredlow and Otto (2015) focused on the valence of the interfering material and its match with the valence of the original memory, whereas the current study focused on the arousing features of the interfering material and its ability to reduce the arousal associated with the original memory. Indeed, this discrepancy may point to a potential research avenue that combines both approaches, i.e., a study design that incorporates both the valence of the interfering material as well as its ability to reduce arousal.

Our results raise a concern relevant to memory reconsolidation in treatment of trauma-related disorders. The hallmarks of such disorders are intrusive memories with vivid imagery and intense anxiety (McNally, 2003). An effective treatment should reduce vividness and anxiety while preserving memories so that patients are able to recall them without distress. Yet our results suggest the opposite pattern — participants could recall the memories just as vividly (though not as anxiously), but could not recall the details as accurately. Hence, more research is needed to elucidate the mechanisms of the reconsolidation of vividness and anxiety of emotional episodic memories.

Finally, the study has limitations. First, our use of undergraduate students precludes generalizations to clinical populations. The second limitation concerns the stimuli. Although videos mimic the dynamic and contextualized nature of episodic memories (Furman et al., 2007), they are nonetheless not real-life episodes. On the other hand, using video clips confers an advantage of controlling and standardizing stimuli across participants as memories of everyday events are variable and seldom subject to standardization (Furman et al., 2007). A third limitation concerns the mechanism through which the neutral video reduced the arousal associated with the stressful video. Although we cited evidence showing that neutral videos reduce arousal, we did not test this ourselves on Day 2. Indeed, had we done so, we would have reactivated their memories of the stressful video by asking participants about their arousal associated with this video, thereby confounding the results by giving every group a reminder. Therefore, we had to assume that the neutral video on Day 2 reduced participants' arousal to the stressful video.

An additional concern is the duration of the study. The study was conducted in three consecutive days. Although this design satisfied the requirements for testing reconsolidation interference (Agren, 2014), it did not test long-term memories that were more than two days old. Future studies need to substantiate the findings by using longer intervals (e.g., 7 days).

The study has implications for research in the reconsolidation of negative episodic memories. It is the first study that used videos and found memory accuracy reduction during reconsolidation of negative episodic memories. It replicated the findings of previous studies, without relying on propranolol (Schwabe et al., 2013) or ECT (Kroes et al., 2014). Additionally, because the study attempted to reduce the memory-enhancing effect of negative emotions, its results may have implications for treating syndromes of anxiety

[2] In addition, our results cannot be explained by evaluative conditioning whereby an originally neutral stimulus acquires the valence of a positive or negative stimulus repeatedly paired with it. In this study, the original stimulus (i.e., the stressful video) was not neutral. Also, we did not test participants' attitude (i.e., liking) of the stressful video after its pairing with either a positive or a negative video.

disorders such as posttraumatic stress disorder.

Declaration of interest

The authors declare no competing financial interests.

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References

Agren, T. (2014). Human reconsolidation: a reactivation and update. *Brain Research Bulletin, 105*, 70–82. http://dx.doi.org/10.1016/j.brainresbull.2013.12.010.

Coccoz, V., Maldonado, H., & Delorenzi, A. (2011). The enhancement of reconsolidation with a naturalistic mild stressor improves the expression of a declarative memory in humans. *Neuroscience, 185*, 61–72. http://dx.doi.org/10.1016/j.neuroscience.2011.04.023.

Di Bona, V. J. (Director). (1989). America's Funniest Home Videos. [Television series]. California: ABC Entertainment.

Dudai, Y. (2004). The neurobiology of consolidations, or, how stable is the engram? *Annual Review of Psychology, 55*, 51–86. http://dx.doi.org/10.1146/annurev.psych.55.090902.142050.

Eldridge, L. L., Sarfatti, S., & Knowlton, B. J. (2002). The effect of testing procedure on remember-know judgments. *Psychonomic Bulletin & Review, 9*, 139–145.

Faul, F., Erdfelder, E., Buchner, A., & Lang, A.-G. (2009). Statistical power analyses using G*Power 3.1: tests for correlation and regression analyses. *Behavior Research Methods, 41*, 1149–1160. http://dx.doi.org/10.3758/BRM.41.4.1149.

Furman, O., Dorfman, N., Hasson, U., Davachi, L., & Dudai, Y. (2007). They saw a movie: long-term memory for an extended audiovisual narrative. *Learning & Memory, 14*, 457–467. http://dx.doi.org/10.1101/lm.550407.

Gross, J. J., & Levenson, R. W. (1995). Emotion elicitation using films. *Cognition & Emotion, 9*, 87–108. http://dx.doi.org/10.1080/02699939508408966.

Hupbach, A., Gomez, R, Hardt, O., & Nadel, L. (2007). Reconsolidation of episodic memories: a subtle reminder triggers integration of new information. *Learning & Memory, 14*, 47–53. http://dx.doi.org/10.1101/lm.365707.

Hupbach, A., Hardt, O., Gomez, R., & Nadel, L. (2008). The dynamics of memory: context-dependent updating. *Learning & Memory, 15*, 574–579. http://dx.doi.org/10.1101/lm.1022308.

Kensinger, E. A., & Schacter, D. L. (2008). Memory and emotion. In M. Lewis, J. M. Haviland-Jones, & L. F. Barrett (Eds.), *Handbook of emotions* (3rd ed., pp. 601–617). New York, NY: Guilford Press.

Kindt, M., & Soeter, M. (2013). Reconsolidation in a human fear conditioning study: a test of extinction as updating mechanism. *Biological Psychology, 92*, 43–50. http://dx.doi.org/10.1016/j.biopsycho.2011.09.016.

Kredlow, M. A., & Otto, M. W. (2015). Interference with the reconsolidation of trauma-related memories in adults. *Depression and Anxiety, 32*, 32–37. http://dx.doi.org/10.1002/da.22343.

Kroes, M. C. W., Tendolkar, I., van Wingen, G. A., van Waarde, J. A., et al. (2014). An electroconvulsive therapy procedure impairs reconsolidation of episodic memories in humans. *Nature Neuroscience, 17*, 204–206. http://dx.doi.org/10.1038/nn.3609.

Kubrick, S. (Producer), & Kubrick, S. (Director). (1980). The Shining. [Motion picture]. United States: The Producer Circle Co.

Magidson, M. (Producer), & Fricke, R. (Director). (1993). Baraka. [Documentary]. United States: The Samuel Goldwyn Company.

Mathot, S., Schreij, D., & Theeuwes, J. (2012). OpenSesame: an open-source graphical experiment builder for the social sciences. *Behavior Research Methods, 44*, 314–324. http://dx.doi.org/10.3758/s13428-011-0168-7.

McGaugh, J. L. (2000). Memory-a century of consolidation. *Science, 287*, 248–251.

McNally, R. J. (2003). *Remembering trauma*. Cambridge, MA: The Belknap Press of Harvard University Press.

Monfils, M.-H., Cowansage, K. K., Klann, E., & LeDoux, J. E. (2009). Extinction-reconsolidation boundaries: key to persistent attenuation of fear memories. *Science, 324*, 951–955. http://dx.doi.org/10.1126/science.1167975.

Nader, K., Schafe, G. E., & LeDoux, J. E. (2000). Fear memories require protein synthesis in the amygdala for reconsolidation after retrieval. *Nature, 406*, 722–726.

Nies, A. S., & Shand, D. G. (1975). Clinical pharmacology of propranolol. *Circulation, 52*, 6–15. http://dx.doi.org/10.1161/01.CIR.52.1.6.

Phelps, E. A. (2004). Human emotion and memory: interactions of the amygdala and hippocampal complex. *Current Opinion in Neurobiology, 14*, 198–202. http://dx.doi.org/10.1016/j.conb.2004.03.015.

Sara, S. J. (2000). Retrieval and Reconsolidation: toward a neurobiology of remembering. *Learning & Memory, 7*, 73–84. http://dx.doi.org/10.1101/lm.7.2.73.

Schiller, D., Kanen, J. W., LeDoux, J. E., Monfils, M.-H., & Phelps, E. A. (2013). Extinction during reconsolidation of threat memory diminishes prefrontal cortex involvement. *Proceedings of the National Academy of Sciences, 110*, 20040–20045. http://dx.doi.org/10.1073/pnas.1320322110.

Schwabe, L., Nader, K., & Pruessner, J. (2013). ß-Adrenergic blockade during reactivation reduces the subjective feeling of remembering associated with emotional episodic memories. *Biological Psychology, 92*, 227–232.

Schwabe, L., & Wolf, O. T. (2009). New episodic learning interferes with the reconsolidation of autobiographical memories. *PLoS ONE, 4*, e7519. http://dx.doi.org/10.1371/journal.pone.0007519.

Sharot, T., Delgado, M. R., & Phelps, E. A. (2004). How emotion enhances the feeling of remembering. *Nature Neuroscience, 7*, 1376–1380. http://dx.doi.org/10.1038/nn1353.

Zillmann, D., & Johnson, R. C. (1973). Motivated aggressiveness perpetuated by exposure to aggressive films and reduced by exposure to nonaggressive films. *Journal of Research in Personality, 7*, 261–276. http://dx.doi.org/10.1016/0092-6566(73)90041-X.