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Cue-independent forgetting by intentional suppression – Evidence for inhibition as the mechanism of intentional forgetting

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ABSTRACT

People are able to intentionally forget unwanted memories through voluntary suppression, as revealed by the Think/No-think (TNT) paradigm. However, the nature of intentional forgetting is controversial. Findings that forgetting is independent of retrieval cues suggest that inhibitory control underlies intentional forgetting, but this result is also in line with an interference account. To resolve this controversy, we have directly contrasted the cue-independent characteristic of suppression versus interference. A double-cue paradigm was used, in which two different cues were associated with the same target during initial memory formation. Only one cue-target association received further interference/suppression training. In the test phase, when both cues were used to retrieve the target, we found that interference caused memory impairment that was restricted to the trained cue-target association, while suppression induced forgetting that generalized to the independent cue-target association. Therefore, the effect of suppression differs from that of interference. The cue-independent forgetting by voluntary suppression indicates that the target memory itself is inhibited, providing evidence that the underlying mechanism of suppression-induced forgetting is inhibitory control.

1. Introduction

Memory can be established and lost dynamically in one's lifetime. While a particular memory is often intentionally established, how this memory can be intentionally forgotten remains an open question. In order to address this question, Anderson and Green (2001) developed a Think/No-think (TNT) paradigm and found that not thinking about a memory impaired its later retention, thus demonstrating that humans can selectively repress certain memories and forget them voluntarily.

In the TNT paradigm, subjects first study a list of unrelated cue-target word pairs (e.g., ordeal-roach). Then, they perform a Think/No-think task in which, when the cue words from a subset of word pairs are presented, subjects either recall the associated target item or inhibit it from entering their conscious. Finally, memory for all of the target words is tested (e.g., ordeal-r__). Results have shown that recall for the suppressed targets is worse than recall for the baseline targets (on which neither Think nor No-think training has been given), providing the first evidence that intentional suppression is able to cause memory impairment (e.g., Benoit & Anderson, 2012; Bergstrom, de Fockert, & Richardson-Klavehn, 2009; Depue, Curran, & Banich, 2007; Joormann, Hertel, LeMoult, & Gotlib, 2009; Kim & Yi, 2013; Lambert, Good, & Kirk, 2010; Levy & Anderson, 2008; Racsmany, Conway, Keresztes, & Krajcsi, 2012; van Schie, Geraerts, & Anderson, 2013; Waldhauser, Lindgren, & Johansson, 2012).

Anderson and Green (2001) suggested that the underlying mechanism of voluntary suppression was different from that of the traditional interference approach. While interference uses new associations to disrupt the original cue-target association (e.g., in Fig. 1, alternative associations (1) interrupt the original association (2)), suppression requires inhibitory control of the target memory (e.g., in Fig. 1, suppressing target memory (3) directly). Therefore, forgetting by suppression should be independent of retrieval cues, which is not the case for interference. In order to test this hypothesis, they used a critical independent-cue technique, in which new cues that were semantically (not experimentally) associated with the target were used for retrieval in the test phase (e.g., insect-r__) (Anderson & Spellman, 1995). Subsequent research using this independent-cue technique showed that memory was

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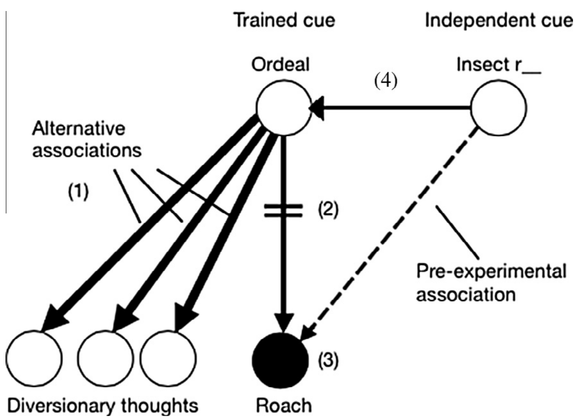

Fig. 1. Possible mechanisms of the TNT paradigm (Anderson & Green, 2001).

still impaired for voluntarily suppressed targets (Anderson & Green, 2001; Benoit & Anderson, 2012; Bergstrom et al., 2009; Levy & Anderson, 2008). Given that these cues were supposedly independent of any associations formed during the experiment, these findings suggested that the suppression effect was not due to the blocking of the cue-target association and thus seemed to eliminate the role of the interference account in intentional forgetting.

However, recent studies have suggested that under certain circumstances, the cues used in the independent-cue technique may not be as independent as was assumed. Researchers suggested that subjects might think of and covertly retrieve the originally trained cues during the independent-cue test (Camp, Pecher, & Schmidt, 2005; Perfect et al., 2004). For example, Camp, Pecher, Schmidt, and Zeelenberg (2009) used independent cues and found that participants showed an increase in memory recall for items paired with better-memorized trained cues. Because only the trained cues were manipulated in the experiment, independent-cue tests may have been influenced by the accessibility of the trained cues (arrow (4) in Fig. 1), which suggests that the target words may have been retrieved via an independent cue—trained cue—target word pathway. If this is the case, there is no clear difference between the independent-cue test and the trained-cue test, which would suggest that memory impairment found in the TNT paradigm could still be caused by associative interference. This covert cuing explanation has been questioned recently by Weller, Anderson, Gomez-Ariza, and Bajo (2013), who showed that deliberately engaging in covert cuing decreased rather than increased the forgetting effect for independent-cue tests. Although Weller et al.'s (2013) study was not directly testing for intentional forgetting, their results led us to consider the covert-cuing explanation for the TNT paradigm.

In this study we used a double-cue technique to test the roles of inhibition, interference, and covert cuing in intentional forgetting. In this double-cue technique (Table 1), two different cues were paired separately with one common target (e.g., A-T, B-T) for learning, but only one cue-target association received interference (e.g., A_1-*Distractor*) or inhibition training (e.g., A_2-No-think). To test the cue-independent quality of interference- or inhibition-caused forgetting, both cues were used to retrieve the target item (e.g., A-?, B-?). Our hypotheses are as follows: (1) If the No-think instruction is simply creating a form of interference, there should be no difference in the pattern of forgetting between the interference and inhibition conditions. Given that associative interference interrupts the trained cue-target associations, the forgetting effect should be restricted to the trained-cue retrieval. (2) If covert cuing is also in operation, as was claimed by Camp et al. (2009), cue-independent forgetting should also be observed in the interference condition. Thus, if both conditions produce forgetting on both the trained- and the independent-cue test, the data would favor the covert-cuing account and the non-inhibitory theories associated with covert-cuing. (3) However, if forgetting was cue-dependent for interference but cue-independent for No-think training, this would implicate that an additional inhibitory control procedure was happening to the No-think training.

Table 1
Procedure for the interference/inhibition paradigm.

	Learning	Interfere/inhibit training	Test phase: Trained cue	Test phase: independent cue
Interference	A_1-T_1; B_1-T_1	A_1-*Distractor*$_1$	A_1-?	B_1-?
Inhibition	A_2-T_2; B_2-T_2	A_2-No-think	A_2-?	B_2-?
Control	A_3-T_3; B_3-T_3		A_3-?	B_3-?

* A and B represent different cue words, and T represents the common target words; numbers are used here only to signify that words in different conditions are from different subsets.

2. Method

2.1. Participants

Thirty-one subjects (22 female, aged 18–27) were recruited from Peking University, Beijing, China. They were all native Chinese speakers with normal reading and comprehension ability.

2.2. Materials

Forty-eight unrelated Chinese word pairs (e.g., *wisdom-earring*) with relatedness less than 2.5 (as rated on a 7-point Likert scale by 23 subjects who were naïve regarding the aim of the experiment) were used for learning and testing. Each target word was paired with two different cue words (e.g., *wisdom-earring and gardener-earring*), thus two series, 24 word pairs each, in the form of A-T and B-T, were generated. The word pairs were divided into three subsets, which were rotated across subjects through the conditions (interference, inhibition, and control). Relatedness, familiarity (as rated by 100 subjects on a 7-point Likert scale), stroke number, and word frequency (from the Corpus for Modern Chinese Research (Sun, Sun, Huang, Li, & Xing, 1996), which has collected 1.24 million words from a broad range of genres) were balanced across each condition ($p > .05$).

Distractors that were used for interference training consisted of 24 words that were not associated with the cue words. Each distractor was paired with a certain cue word in A-T pairs (e.g., *wisdom-skating*). Accordingly, the 24 distractors were divided into three subsets, and only one subset was used for each subject.

2.3. Procedure

This experiment was an adaptation of the TNT paradigm. It consisted of three phases: associative learning, interference/inhibition training, and testing (Table 1). There were two major differences from the TNT paradigm. First, double-cue/one-target pairs were learned and tested; second, in the second phase, we replaced the Think training with interference training by pairing the trained cue with a distractor.

2.3.1. Associative learning

Forty-eight word pairs (24 A-T and 24 B-T pairs) were presented individually, each for 3 s. After first learning, subjects had to do a self-test with corrective feedback. During the self-test, each cue word was presented first, and subjects were required to recall the target word. Then, they pressed the space key to get the correct answer and reported whether their answer was correct. The self-test phase lasted until subjects reached 91.67% (22 out of 24) accuracy for both A-T and B-T pairs so as to ensure that memory strength was strong for both series and for all of the subjects.

2.3.2. Interference/Inhibition training

Sixteen A-T word pairs were used for two divergent tasks: eight for interference and eight for inhibition training. Each cue word was first presented on the left side of the computer screen for 1 s. Then, the word turned red. In the interference condition, a substitute word appeared on the right side of the computer screen, and subjects were asked to memorize the new word pair (A-*Distractor*) in 4 s; in the suppression condition, no target word was shown, and the cue word remained on the screen for 8 s. Subjects were instructed to not think about the original target word, and two critical points were emphasized during the suppression condition. First, in order to achieve the inhibition effect, we asked subjects to initiate the suppression after they had an impulse to retrieve the target word. Second, subjects were required to not think about other distracting things. Both interference and inhibition trainings were repeated 12 times, with 192 trials in total. Compliance with instructions was checked after training, and all of the subjects reported that they had followed the above instructions correctly.

2.3.3. Testing

We tested subjects' memory for all of the word pairs learned during the first phase (A-?; B-?). Cue words from different conditions were intermixed and shown sequentially; subjects were asked to recall the corresponding target word by typing it on the computer keyboard, with no time limit. The order of testing for the trained- and independent-cue tests were counterbalanced across items and within subjects.

3. Results

We calculated the mean percentage of target words that were recalled during the final test. A 2 (test type: trained-cue vs. independent-cue) × 3 (treatments: interference, inhibition, control) repeated measures ANOVA was employed. Results (Fig. 2) showed that, the main effect of test type ($F(1,30) = 17.70$, $p < .001$, $MES = 0.03$, $\eta^2_p = 0.37$) was significant, with stronger memory impairment for under trained- than independent-cue retrieval. The main effect of treatment ($F(2,60) = 10.52$, $p < .001$, $MES = 0.03$, $\eta^2_p = 0.26$) was also significant. As expected, when compared to the control condition, both interference ($MD = -0.95$, $p = .012$) and inhibition ($MD = -0.13$, $p < 0.001$) caused target memory impairment.

The interaction effect of the two factors was also significant ($F(2,60) = 3.20$, $p = .048$, $MES = 0.03$, $\eta^2_p = 0.10$). Simple effects analyses showed differences between the effects of interference and inhibition training. In the interference condition, memory impairment was only found under the trained-cue retrieval (A-T: interference < control, $t(30) = -3.43$, $p = .002$) but not under the independent-cue retrieval (B-T: interference < control, $t(30) = -0.52$, $p = .608$). In contrast, in the inhibition condition, memory impairment was found in both the trained-cue (A-T: inhibition < control, $t(30) = -4.90$, $p < .001$) and the independent-cue (B-T: inhibition < control, $t(30) = -2.79$, $p = .009$) tests. In addition, memory performance was not different between the two test types ($t(30) = -1.88$, $p = .071$) following inhibition training.

To further discriminate the effects of inhibition and interference, we calculated the percentage of forgotten items for the trained-cue test that generalized to the independent-cue test. If

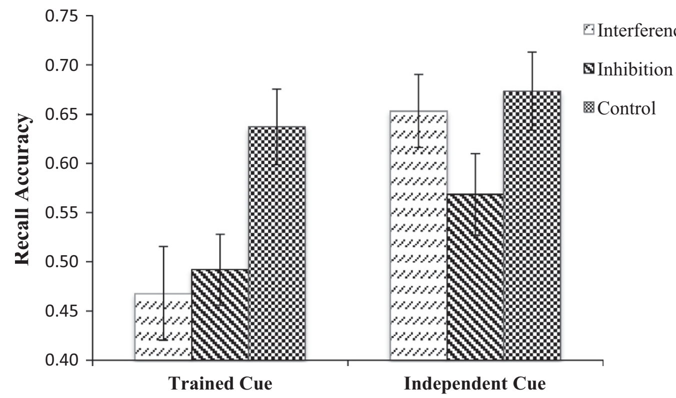

Fig. 2. Recall accuracy for each test type and each training condition. Error bars represent standard errors of the recall accuracy.

intentional suppression indeed works on the target memory itself, items that failed to be retrieved in the trained cue-target associations should also be forgotten in the independent cue-target associations. The generalization index was calculated by dividing the percentage of items that were forgotten in the trained-cue test from that in both the trained- and independent-cue tests. The percentage of generalization was different across the three conditions ($F(2,48) = 3.75$, $p = .03$, $MES = 0.06$, $\eta^2_p = 0.14$). As expected, generalization was significantly higher in the inhibition condition than in the interference condition ($t(24) = -3.93$, $p < .001$), confirming the cue-independent nature of intentional inhibition.

4. Discussion

In this study, we used a double-cue paradigm to explore the underlying mechanism of intentional forgetting. Results show differences between the effect of intentional suppression and associative interference. Intentional suppression causes generalized memory impairment, as accessibility of the target memory is reduced for both the trained and the independent cues. In contrast, interference training only affects the directly trained cue-target association. As forgetting by intentional suppression is independent of the cue, it is in line with findings from Anderson and colleagues (Anderson, 2005; Anderson & Green, 2001; Anderson et al., 2004) which showed that intentional suppression impairs only the target memory.

Although the cue-independent forgetting has long been used to support the role of inhibitory control in intentional forgetting (e.g., Anderson & Green, 2001; Anderson et al., 2004; Benoit & Anderson, 2012), some have argued that it reflects interference mechanisms driven by covert cuing (Camp et al., 2009). However, as Weller et al. (2013) have reasoned, if the independent cue covertly retrieved the trained cue during test, it would also result in blocking on the cue-target association as well and further memory impairment. Yet their findings showed that deliberately recruiting covert cuing did not cause but masked the cue-independent forgetting, and therefore strongly opposed the covert-cuing explanation for independent-cue technique. While Weller et al.'s (2013) study was on retrieval-induced forgetting (RIF) effect, here we tested the covert-cuing explanation in relation to the TNT paradigm and intentional forgetting. By directly comparing the effects of interference and suppression training, different patterns of forgetting were revealed. Therefore, we rejected the role of covert-cuing in intentional forgetting. In this way, the covert-cuing explanation for independent-cue retrieval was excluded consistently by different experimental approaches.

Benoit and Anderson (2012) compared the effect of direct suppression with a procedure that trained subjects on thought substitutes. In contrast to the present findings, they found cue-independent forgetting effects in the thought substitution condition. However, this finding may be because of the difference between their manipulation and the one used in the current study. In Benoit and Anderson's (2012) study, participants first memorized a list of substitute associations, and during the training session, they retrieved the substitute words repeatedly to prevent the original memory from entering their mind. This type of manipulation is in line with the RIF procedure, where retrieving a related memory suppressed the original memory. As a result, the manipulation of thought substitution is a type of inhibition rather than interference training. In the interference training in the current study, substitutes were given directly to participants and no retrieval was required, thus ensuring against any potential inhibition caused by retrieval practice. This manipulation was similar to the repeated study trainings in RIF studies which have been confirmed to cause no inhibition (Dobler & Bauml, 2013; Hulbert, Shivde, & Anderson, 2012). Therefore, the current finding did not contradict previous findings, and the cue-dependent forgetting by associative interference is consistent with traditional interference theories. In the No-think training from the current study, directions for direct suppression were the same as in previous studies (Benoit & Anderson, 2012; Bergstrom et al., 2009). Such strict instructions minimize the development of alternative associations during the No-think training, making it very unlikely that forgetting (on either the trained- or independent-cue test) in this and prior studies was caused by interference caused by alternative thoughts.

Although suppression-induced forgetting opens a new avenue to the study of intentional forgetting, some studies have failed to find this effect (e.g., Bulevich, Roediger, Balota, & Butler, 2006; Hertel & Calcaterra, 2005; Hertel & Gerstle, 2003). In our opinion, this failure to replicate may be due to the differences in the timing of the suppression. Based on our experience, it is essential to first initiate an impulse to retrieve the memory and then inhibit the memory; if inhibition is initiated immediately after the impulse to retrieve the memory, there is a greater likelihood of intentional forgetting. Therefore, the key of the inhibition task (i.e., the No-think task in the TNT paradigm) is not to "not think"; rather, the key is the suppression of the impulse to retrieve the target memory. These findings complement the idea that inhibition responds to intrusions (Anderson & Hanslmayr, 2014; Benoit, Hulbert, Huddleston, & Anderson, 2015; Levy & Anderson, 2012). As revealed by an fMRI study (Levy & Anderson, 2012), hippocampal activity, which represents the forgetting effect by suppression training, is primarily down-regulated during memory intrusions. Consequently, the "impulse to retrieve" may be essential for intentional suppression.

Inhibition-induced forgetting generalizes to other retrieval cues, while interference-caused forgetting is restricted to directly interfered cue-target association. This type of difference has also been found in working memory studies on both declarative and procedural memory (Oberauer, Souza, Druey, & Gade, 2013). The generalized memory impairment by voluntary inhibition suggests the feasibility of interrupting daily life memories, which are linked with various contextual cues. An increasing amount of attention has been directed toward research on intentional inhibition and its potential relevance in understanding and treating clinical disorders (e.g., Anderson, Reinholz, Kuhl, & Mayr, 2011; Joormann et al., 2009; Kupper, Benoit, Dalgleish, & Anderson, 2014; van Schie et al., 2013; for a review see Anderson & Huddleston, 2012). Future attempts should determine whether intentional inhibition is also effective for remote memories.

In conclusion, our study resolves the controversy of inhibition versus interference in regard to intentional forgetting. We demonstrate that inhibition is an inherently distinct process from interference and it is the underlying mechanism of intentional forgetting. As forgetting by inhibition is independent of retrieval cues, it may be a promising way to help people forget unwanted memories.

5. Declaration

Our manuscript is original, has not been previously published, and is not currently under consideration elsewhere.

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