An interference account of cue-independent forgetting in the no-think paradigm

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Memory suppression is investigated with the no-think paradigm, which produces forgetting following repeated practice of not thinking about a memory [Anderson MC, Green C (2001) *Nature* 410:366–369]. Because the forgotten item is not retrieved even when tested with an independent, semantically related cue, it has been assumed that this forgetting is due to an inhibition process. However, this conclusion is based on a single stage to recall, whereas global memory models, which produce forgetting through a process of interference, include both a sampling and a recovery stage to recall. By assuming that interference exists during recovery, these models can explain cue-independent forgetting. We tested several predictions of this interference explanation of cue-independent forgetting by modifying the think/no-think paradigm. We added a condition where participants quickly pressed enter rather than not thinking. We also manipulated initial memory strength and tested recognition memory. Most importantly, learning to quickly press enter produced as much cue-independent forgetting as no-think instructions. Demonstrating the adequacy of two-stage recall, a simple computational model (SAM-RI) simultaneously captured the original cue, independent cue, and recognition results.

cued recall | inhibition | recall | recognition | computational model

Whether failing to recall an item on a shopping list or an important anniversary, forgetting can be a frustrating experience. However, there are some memories that people may want to forget. Freud theorized that people could willfully forget unwanted memories through a process of repression that pushes memories into the unconscious (1). To explain experimental results involving control of unwanted memories, Anderson and Green (2) proposed a theory based on active inhibition in which inhibition of unwanted memories is an executive control process that prevents memories from entering consciousness (2–4). This theory of controlled inhibition is one example from a class of inhibition accounts that have been applied in different areas of memory research. For instance, inhibition theory inspired a new mathematical model for studying memory (5), and many forgetting effects have been interpreted in terms of inhibition (3, 6–13).

However, forgetting through inhibition is a departure from decades of research suggesting that forgetting occurs through interference. In interference theory, it is the learning of something else that causes forgetting: the original memory is difficult to access because of the learning of other memories that compete with each other during retrieval. These theories explain a wide range of phenomena, such as effects of list length and part-set cueing (14), list strength (15), false memory (16), and articulatory suppression (17). In light of the many successful applications of interference-based theories, it is important to consider whether results with "inhibition paradigms" are equally compatible with interference explanations. Therefore, the current study applies a successful interference model—the Search of Associative Memory (SAM) model of recall (14)—to explain results previously attributed to active inhibition.

Interference-based global memory models (18, 19), such as SAM, assume that recall consists of a sampling stage that locates the memory, followed by a recovery stage that retrieves the details of the memory. This distinction is thought to underlie the tip-of-the-tongue (TOT) phenomenon (20), in which one is aware that a memory is known (i.e., a memory is sampled) but cannot fully recover the memory. By including interference in the recovery stage of recall, we demonstrate that this model explains results previously thought to uniquely indicate inhibition. The reported experiment tests and confirms qualitative and quantitative predictions of this account, demonstrating that interference theory not only explains a wide variety of memory effects, but can also explain findings obtained in a paradigm that have been attributed to active inhibition.

The think/no-think (TNT) procedure of Anderson and Green (2) was developed to study the active inhibition of memories, so we focused on this seminal paradigm to demonstrate the explanatory power of interference in the second stage of recall. In this paradigm (Fig. 1 and Fig. S1), participants first learn to associate two unrelated words, e.g., "plane–doctor." Next, participants are instructed that it is undesirable to recall "doctor" in response to "plane" and when presented with the cue word "plane" they should stop the target word "doctor" from entering their conscious thought. During this suppression training participants practice by spending 4 seconds not thinking about the target each time the cue appears. Subsequently, there is a decreased probability of recalling "doctor" when presented with "plane" even though instructions encourage recall (2).

The finding that it is difficult to retrieve the target word after no-think training is compatible with an interference explanation with one-stage recall, such as is shown in Fig. 2 *Upper*. If people learn to associate the cue "plane" with some other response, such as sitting quietly for 4 seconds, this will serve as a competitor to the original memory. However, Anderson and Green (2) also tested memory with independent cues (i.e., not previously studied) designed to retrieve the original memory through semantic association. For instance, participants are presented with "nurse" and told to attempt to retrieve one of the target words. Because the other response learned during no-think training is associated with "plane" and not "nurse," there should be no interference with this independent cue. Therefore, one-stage interference models cannot explain the finding that forgetting also exists for this independent cue test (2, 12; although for a failure to find no-think forgetting, see ref. 21).

Cue-independent forgetting is explained easily by the assumption that the target memory is inhibited, resulting in poor memory regardless of the cues used to test memory. For this

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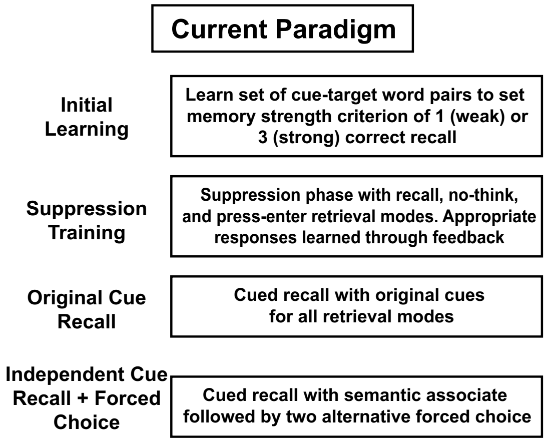

Fig. 1. Current methodology as adapted from the TNT paradigm by Anderson and Green (2).

reason, it has been assumed that cue-independent forgetting is the unique signature of memory inhibition. This assumption is important because it relates to the interpretation of both behavioral and brain imaging studies. For example, relative reductions of neural activation in the no-think condition have been interpreted as reflecting neural inhibition, rather than interference (12, 22, 23). Therefore, the validity of the inhibition account of the behavioral data is of great significance and directly relates to the proper interpretation of neural recordings. This assumption is also important considering that the TNT and related inhibition paradigms have been used in linguistic applications (24) and directed forgetting with single-item and multiple study lists (3, 6). Therefore, we ask whether interference theory can equally explain cue-independent forgetting in the TNT paradigm. If so, this weakens the assumption that cue-independent forgetting necessarily implies inhibition. Our goal is not to falsify

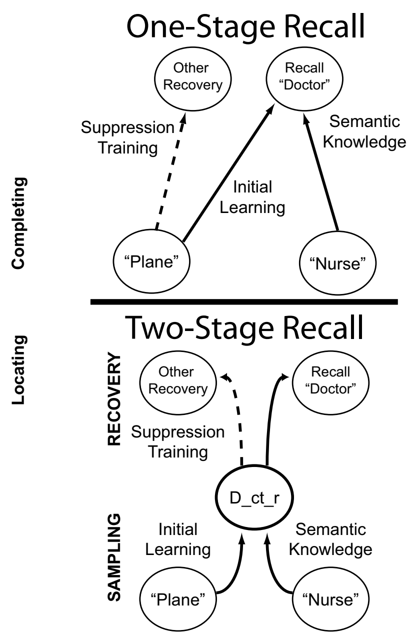

Fig. 2. One-stage (*Upper*) versus two-stage (*Lower*) models of cued recall. For both models, the initially learned association between ''Plane'' and ''Doctor'' is represented by solid lines. The dashed lines between ''Plane'' and ''Other Recovery'' represent the newly learned association during suppression training, as in the no-think and press-enter conditions.

inhibition theory; rather, we propose an alternative account based on interference and test predictions of this account.

If recall consists of a single stage, then interference theory cannot explain cue-independent forgetting. However, global memory models have always assumed two stages to recall: First, a memory must be sampled, then a recovery attempt is made for the contents of the sampled memory. These two stages are shown in Fig. 2 *Lower*, in which the sampled memory of "doctor" is an incomplete representation (illustrated by "d_ct_r") and requires full recovery to produce the verbal response. The current context combined with any specific cues presented at study are used to locate (i.e., sample) a particular memory trace, and interference in sampling has explained many memory effects. However, global memory models also posit a recovery stage to explain why some classes of objects (e.g., low-frequency words) are more difficult than others to recall (25–27). Although interference within the recovery process was not previously needed in these models, it follows naturally from their core assumptions. As seen in Fig. 2 *Lower*, participants may occasionally sample the partial memory trace during no-think training but then learn to associate this memory trace with the no-think response (i.e., sitting quietly). It is important to note that this sampling of the target during no-think training is in opposition to the task instructions to suppress the target in response to the cue. However, if the cue and target are well-learned in the first stage, then the target may be automatically sampled on some trials. To the extent that this automatic sampling happens, the newly learned association between "d_ct_r" and "sitting quietly" will produce cue-independent forgetting because regardless of how the partial memory is sampled at final test, it will suffer from interference in the recovery process. Thus, a two-stage model of recall can produce cue-independent forgetting through a process of learned avoidance rather than directed inhibition.

To demonstrate the viability of this recovery interference account, we tested three predictions within the TNT paradigm. First, and most importantly, this account predicts that any learned alternative recovery can produce cue-independent forgetting provided that memory is occasionally sampled during the suppression training. Thus, there is nothing special about having participants actively suppress the target memory for 4 seconds. Instead, the important aspect is that people are instructed to do something else besides identify and recover the verbal label of the target. We tested this by comparing the usual no-think instructions to a condition in which participants were given no suppression instructions and were instead told to press the enter key as quickly as possible.

A second prediction of recovery interference is release from interference. An assumption of interference theory is that the target memory is intact but difficult to retrieve because of competition. Thus, it should be possible to produce a release from recovery interference by providing the identity of the target memory, which eliminates the need to engage in recovery. This is achieved with recognition testing at the end of the experiment. The recovery interference model predicts no difference in recognition performance between the "suppression conditions" (no-think and press-enter) compared with a baseline condition of word pairs not seen during suppression training. This is because recognition is based on an association between the target item itself and the latent memory trace, and in none of these conditions is the target item seen or recovered during suppression training.

Finally, recovery interference makes quantitative predictions for the degree of forgetting and initial memory strength. Assuming the same degree of learned recovery for an alternative response regardless of initial cue-target memory strength (the *Discussion* considers alternatives to this simplifying assumption), recovery interference predicts that initially weak memories should suffer more forgetting compared with initially strong

Table 1. Observed and simulated mean accuracy by task, condition, and memory strength

Retrieval type	Recall	No-think	Press-enter	Baseline
Strong Memory Strength				
Original cue recall	0.96 (0.02) 0.96	0.83 (0.02) 0.81	0.82 (0.02) 0.81	0.86 (0.02) 0.87
Independent cue recall	0.49 (0.02) 0.54	0.48 (0.02) 0.48	0.45 (0.02) 0.48	0.50 (0.02) 0.51
Forced-choice recognition	0.96 (0.01) 0.96	0.95 (0.01) 0.95	0.96 (0.01) 0.95	0.94 (0.01) 0.95
Weak memory strength				
Original cue recall	0.95 (0.02) 0.95	0.60 (0.02) 0.65	0.62 (0.02) 0.65	0.73 (0.02) 0.73
Independent cue recall	0.50 (0.02) 0.54	0.44 (0.02) 0.41	0.49 (0.02) 0.41	0.54 (0.02) 0.47
Forced-choice recognition	0.96 (0.01) 0.96	0.92 (0.01) 0.92	0.93 (0.01) 0.92	0.94 (0.01) 0.92

The first value is observed accuracy. Observed SEM is given in parentheses. The last value is predicted accuracy.

memories. This prediction follows if the probability of retrieval is based on the relative strengths of different memories, such as with competitive sampling among possible memories. For instance, if some Other response (e.g., press-enter) has recovery strength O as learned during suppression training, then a Weak memory (W) is a smaller proportion of the sampling space, $W/(O + W)$, compared with an initially Strong memory, $S/(O + S)$. Further, this effect should be magnified for original cue compared with independent cue testing because original cue testing involves initial memory strength in both the sampling and recovery stages, whereas independent cue testing only includes memory strength in the recovery stage. To test the role of initial memory strength with different types of retrieval, the reported experiment examined (*i*) original cue recall, which includes both sampling and recovery; (*ii*) independent cue recall, which only includes recovery; and (*iii*) self-cue recognition, which only includes sampling. By comparing performance across these three retrieval measures for two levels of initial memory strength, quantitative predictions of recovery interference were tested.

In summary, the reported experiment contained three manipulations to test predictions of a recovery interference account of cue-independent forgetting: (*i*) learning to press enter should be similar to no-think suppression training; (*ii*) recognition testing, which bypasses the need for recovery, should eliminate forgetting effects; and (*iii*) initially weak memories should suffer more forgetting than initially strong memories, particularly with original cue recall. As reported below, each these predictions was confirmed. However, confirming qualitative predictions does not necessarily mean that an account based on recovery interference can quantitatively capture the data patterns across all three forms of testing. Therefore, we report a quantitative application of the recovery interference SAM model to these results.

Results

Suppression Training. When participants learned which of the three tasks to perform for each cue word, performance started out poorly, but by the 19th block, participants reached an average of 84% accuracy (Table S1).* There is an initial tendency for better performance on the recall task, reflecting prior experience with recalling the target words in response to each cue.

Final Test. A 2 (memory strength) × 4 (task type) ANOVA was conducted for each final memory test (original and independent cue recall and forced-choice recognition), followed by appropriate comparison tests. Table 1 shows the full results as well as simulation results from the model. First, we report the main effects of task type and memory strength, followed by interactions. Effect size (ES) values are partial η^2 for F tests and Cohen's d for t tests.

Original Cue Recall. There was a main effect of memory strength on recall accuracy, $F(1,83) = 91.82$; $P < 0.001$; ES = 0.52 (Fig. 3), with lower accuracy in the weak conditions. There was also a main effect of task type on recall accuracy, $F(3,254) = 60.17$; $P < 0.001$; ES = 0.42. Performance in the no-think and press-enter conditions† was significantly lower than baseline, $t(83) = 4.01$; $P < 0.001$; ES = 0.44; and recall conditions, $t(83) = 13.12$; $P < 0.001$; ES = 1.43.

Independent Cue Recall. There was no main effect of memory strength, $F(1,84) = 0.608$; $P = 0.438$, but there was a main effect of task type on independent cue recall, $F(3,254) = 2.64$; $P \leq 0.05$; ES = 0.03.‡ Performance in the no-think and press-enter conditions* was significantly lower than baseline, $t(83) = 2.70$; $P < 0.01$; ES = 0.29, and marginally lower than the recall condition, $t(83) = 1.52$; $P = 0.07$; ES = 0.17.

Forced-Choice Recognition. There was a main effect of memory strength on recognition accuracy, $F(1,84) = 4.37$; $P < 0.05$; ES = 0.05, with lower accuracy in the weak conditions. There was also a main effect of task type on recognition accuracy, $F(3,254) = 2.98$; $P < 0.05$; ES = 0.03. Performance in the no-think and press-enter conditions* was significantly lower than the recall condition, $t(83) = 2.22$; $P < 0.05$; ES = 0.24, but not significantly different from the baseline condition, indicating no impairment in recognition accuracy for the no-think and press-enter conditions. As seen in Table 1, there is a restricted range with recognition accuracy, with what may appear to be a ceiling effect and reduced power to detect differences. However, because there were significant improvements in the recall condition (i.e., in the direction of ceiling), then it should have been possible to observe deficits in the suppression conditions (i.e., in the direction of floor).

Memory Strength Interaction with Task Type. Memory strength did not interact with task type for independent cue recall or forced-choice accuracy, but it did for original cue recall accuracy, $F(3,254) = 14.53$; $P < 0.001$; ES = 0.15. There was a main effect of task type on original cue recall accuracy for both weak, $F(3,277) = 56.9$; $P < 0.001$; ES = 0.38, and strong memories, $F(3,278) = 14.77$; $P < 0.001$; ES = 0.14. To assess the interaction, the difference between the baseline versus the combined press-enter and no-think conditions was used to measure forgetting,

*The accuracy rate at the end of suppression training was lower than in the standard TNT paradigm. This is likely the result of learning three responses (i.e., no-think, press-enter, and think) rather than the standard two responses (i.e., think and no-think).

†Paired comparisons revealed no significant differences between the no-think and press-enter conditions, so these conditions were collapsed for subsequent analyses.

‡It is possible that the independent cue results are not truly "independent," because they may have been affected by the preceding cued recall task. However, there was no feedback during testing, and thus no learning in the model during testing. This proved to be an adequate assumption.

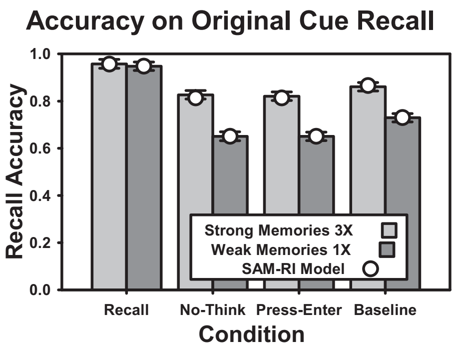

Fig. 3. Original cue recall accuracy by memory strength and suppression task. The circles show data fits with the SAM-RI model based on the parameters reported in the text. Error bars present plus and minus one SEM.

and a comparison of this difference for weak and strong memories revealed greater forgetting for weak memories, $t(83) = 2.60$; $P < 0.01$; ES = 0.28 (Fig. 3).

Results Summary. All of the recovery interference predictions were confirmed: (*i*) press-enter forgetting was equal to no-think forgetting for original and independent cue recall; (*ii*) there was no forgetting in the suppression conditions, as measured with recognition; and (*iii*) memory strength interacted with suppression forgetting as measured with the original cue, revealing more forgetting for initially weak memories compared with initially strong memories. Next, these results were quantified with a recovery interference version of the SAM model. This demonstrated that recovery interference can handle data patterns across all three memory performance measures in a consistent manner.

Search of Associative Memory with Recovery Interference (SAM-RI). Interference accounts of forgetting have been specified with mathematical models, such as SAM, and have been applied both to recall (14) and recognition (28). We developed a modified SAM model to test whether recovery interference is quantitatively accurate in its explanation across the three performance measures. We termed this modified SAM model SAM-RI: Search of Associative Memory with Recovery Interference. We asked whether six parameters (Weak, Strong, Recall, Other, Association, and Variance; Table 1) can be optimized to simultaneously fit the 24 observed average accuracy values (see Fig. S2 for further detail).

We simplified the original recall SAM model by assuming that the proportion of items recalled is the probability of sampling multiplied by the probability of recovery for any given item in that condition, as shown in Eq. **1**. This is not an assumption of independence, because we express recovery as conditional upon sampling.

$$p(recall) = p(sample) * p(recover|sample) \qquad [1]$$

Sampling in SAM follows a Luce choice rule (29), as seen in Eq. **2**, where the probability of sampling a memory trace is the ratio of the strength of association between the cue (C) and the target memory trace (T) to the sample space of possible memory traces.

$$p(sample_i) = \frac{S(C,T_i)}{S(C,T_i) + \Sigma S(C,T_j) + 1} \qquad [2]$$

$S(C,T_i)$ is the experimentally learned strength of association between the cue and the target memory trace; $S(C,T_j)$ is any experimentally learned association between the cue and other memory traces ($j \neq i$); and *1* is a scaling constant that represents the association strength between the cue and memory traces learned before the experiment. Eq. **2** includes this summation over alternative traces for generalization to situations involving multiple targets to the same cue. However, because the memory traces for the learned alternative behaviors (no-think or press-enter) are likely to be contextually bound to the suppression stage of the experiment, the summation for the sampling strength of alternative traces is set to 0. In other words, because participants are instructed during final recall to revert to the original target recall, this may establish a contextually defined sampling space that eliminates any direct connection between the cue and other responses.

Sampling strength depends on the experimental condition and differs for the different cue words that are used to probe memory in the final test: the original, independent, or self-cue. The association strength between an independent cue and the target memory is the same across the four suppression conditions and is set to A for semantic Association. To model learning during the course of the experiment, we assume that learned increases in sampling strength occur with successful sampling. In the initial learning phase, the learned cue-target sampling strengths are set to W for Weak items and S for Strong items. The final sampling strengths for the baseline conditions remain at these values. For the recall condition, the sampling strength is increased by an amount R, reflecting continued Recall practice in response to the original cue. For the suppression conditions, the task instructions are to sit quietly or press enter, and so the target memory is sampled only to the extent that it is unavoidably sampled through automatic processes. A more direct "pathway" involves direct association between the presented cue word and the correct alternative behavior. However, to some degree, or perhaps on some trials, the target memory may be sampled, thus eliciting indirect learning to the press-enter or no-think responses by way of the target memory trace.[§] Because this indirect pathway is likely to be used to a lesser extent, we use the parameter O for the degree of increased sampling of the target in the suppression conditions, and we expect that, in general, O will be less than R.

As seen in Fig. 2 *Lower*, both original and independent cue recalls use the same recovery process, and thus the probability of recovery in both these recall measures is found by Eq. **3**, which follows the same logic as Eq. **2**, only in this case, the terms represent recovery strength between the sampled target (T) and recovered responses (R).

$$p(recover_i|sample_i) = \frac{S(T,R_i)}{S(T,R_i) + \Sigma S(T,R_j) + 1} \qquad [3]$$

The denominator of Eq. **3** is the space of possible recovered responses, which includes the strength of recovery between the target memory trace and the target word, $S(T,R_i)$, as well as the summation of other responses ($j \neq i$) that have been learned in response to the target memory strength, $S(T,R_j)$. As with sampling, the value *1* serves to scale recovery against other competing recoveries learned before the experiment. To simplify, we assume that the same magnitudes of learning exist in the recovery strength values as for the sampling strength values. In

[§]We could model the two pathways with recovery learning each time that a pathway is used. Then, the free parameter that captures recovery interference would be the proportion of trials during suppression training that used the direct pathway (cue→press-enter) versus the indirect pathway (cue→sampled target→press-enter). However, the multiplication of a constant learning rate by this probability is mathematically identical to assigning a single parameter to the amount of recovery learning for the alternative response. Because there is no test in the paradigm that measures the amount of learning for the direct pathway, it did not seem important to include this level of complication in the model.

general, this need not be the case although, as seen below, this simplifying assumption proved to be adequate.[¶] Based on this assumption, the recovery strength values in all conditions are set to W for the Weak conditions and S for the Strong conditions after initial training. Only in the recall condition is there additional practice recovering the target during suppression training, so the recovery strength is increased by R in this condition. In sampling, use of the indirect pathway during suppression training produced additional sampling strength of the target memory trace by the value O for the no-think and press-enter conditions. This same value is used for recovery in these conditions, although for recovery this results in recovery strength for an alternative response rather than the target. Thus, the summation of the $S(T,R_j)$ terms is O in these conditions, whereas it is 0 in the other conditions.

Next, we considered forced-choice recognition, which is based on the sampling strength for the target as cue for itself. As with sampling between cue and target, self-sampling is also set to S for initially Strong items and W for initially Weak items. The same parameters are used because initial training involves answer feedback upon failure to recall, thus allowing learning between the target word and the target memory trace. Similarly, in the Recall condition, the target is continually recalled during suppression training, so the self-sampling strength is increased by the same value R that is used for cue-target sampling. However, in the press-enter and no-think conditions, the target is not recovered, and there is no opportunity to learn additional self-sampling in these suppression conditions. Thus, SAM-RI predicts that there is neither a recognition deficit nor a benefit for the suppression conditions. Because the distractor in the forced choice is another word that is equally associated to the independent cue, its self-sampling strength is set to the parameter A in all conditions.

The SAM model of recognition uses these sampling strength values to specify normally distributed, unequal-variance target and distractor distributions. Thus, SAM is an unequal-variance signal detection model (28). Forced-choice recognition accuracy is found through the distribution of the differences between the target (*tar*) and distractor (*dis*) self-sampling strengths, which results in Eq. **4**.

$$p(correct) = \int_0^\infty \Phi(x,\mu = (tar - dis),\ \sigma^2 = V[tar^2 + dis^2])dx \qquad [4]$$

The integral is over the normal distribution (Φ), with parameters μ and σ, evaluated from 0 to infinity. This calculates the probability that distractor familiarity is less than target familiarity, thus determining forced-choice accuracy rate. The parameter V is a constant of proportionality to specify the amount of normally distributed Variance associated with each additional unit of familiarity, as dictated by the self-sampling strength.

As seen in Table 1 and Fig. 3, the model provides a remarkably accurate fit to all 24 conditions based on these six free parameters. With a χ^2 goodness of fit of 37.86, the SAM model of sampling and recovery is technically rejected (χ-crit = 28.9 for 95% confidence), although we note that the number of data points is quite large (n = 420; 84 participants with five observations per condition), and the fits to the data are numerically close. The best-fitting values are: $V = 0.3$, $A = 1.2$, $W = 5.9$, $S = 13.4$, $R = 31.0$, and $O = 1.0$. Notably, the other response (O) parameter is rather small compared with the recall learning (R) parameter. This low O value is sensible because the other response parameter is only incremented to the extent that people automatically sample the original target memory but then learn to recover the press-enter or no-think response to that memory, rather than directly associating the cue with the press-enter or no-think response.

Discussion

Global memory models of recall include both a sampling and a recovery stage, with interference occurring in the sampling stage. We propose that the addition of interference in the recovery stage can explain situations of cue-independent forgetting. By considering the effect of learning between a partially retrieved memory (i.e., a sampled memory) and the possible completions (recovery process) for that memory, this account supposes that forgetting in the TNT paradigm does not rely on conscious inhibition. Instead, no-think instructions are effective because (*i*) the cue locates a partial memory and (*ii*) rather than recover that memory with the original target, an alternative recovery is learned that competes with the original target. By this account, learning any alternative recovery in response to the cue should be similarly effective in producing cue-independent forgetting. We confirmed this prediction by including a press-enter condition, which produced nearly identical results to the no-think condition.

We also confirmed two other predictions of this recovery interference account. It was predicted that initially strong memories would be less susceptible to recovery interference. Correspondingly, we found less forgetting in the press-enter and no-think conditions for targets that were initially learned to a higher criterion. Further, recovery interference assumes that the target memory is intact, and so the right set of memory cues can release the memory from interference. This was achieved through recognition testing, which bypasses the need for a recovery process because the target word is directly presented. Recognition performance was very high, which in itself is evidence that the purportedly suppressed memories remained intact. Also, as predicted, the press-enter and no-think conditions did not reveal any forgetting, as tested with recognition. Finally, the pattern of results across all three performance measures was found to be consistent with an interference account as revealed by the application of the SAM-RI model to all 24 conditions with the same small set of parameters.

Although these data and the successful application of the SAM-RI model provide support for an interference theory of forgetting, they do not necessarily falsify inhibition theory. Indeed, certain inhibition accounts may be compatible with these results. Instead, we stress that the current results and model provide an existence proof that interference can capture cue-independent forgetting in the TNT paradigm. Therefore, it is no longer appropriate to assume that forgetting in the TNT paradigm is necessarily due to inhibition. With this caveat, hippocampal differences between the recall condition and the no-think condition as measured with fMRI (12) might reflect increased activation in the recall condition (i.e., enhanced recovery) rather than inhibited memory in the no-think condition. Interpretation of this relative difference depends on whether one approaches the data with a theory of learning and competition versus a theory of suppression.

According to the proposed recovery interference account, cue-independent forgetting requires that the target memory is erroneously sampled during suppression training. This will occur to the extent that the initial memory promotes automatic sampling regardless of instructions. Assuming a fixed degree of automatic sampling, it was predicted that initially weak memo-

[¶]For independent cue recall, the model incorrectly predicts better performance for recall than for the baseline condition, because the same R parameter is used for sampling and recovery. In general, sampling and recovery need not be coupled in this fashion. We ran the model with separate learning rates for sampling and recovery in the recall condition, which requires an additional free parameter. Although this model fit the data slightly better, it was not substantially different from the simpler model, so we omitted it for reasons of clarity.

ries would suffer from greater forgetting through recovery interference. For the reported results, this simplifying assumption was adequate. However, in general, this assumption is likely false. If a memory is so weak as to barely exist, then it will fail to produce automatic sampling. More generally, there should be a nonmonotonic relationship between initial memory strength and the degree of forgetting due to recovery interference. For very weak memories, there will be a lack of forgetting because the indirect pathway of automatically sampling the target memory will rarely be used. Instead, there will be a direct association between the cue and the suppression response. Conversely, very strong memories may elicit more recovery learning for the suppression response, but the learned alternative will be insufficient to overpower the initially strong recovery response for the correct target. Thus, cue-independent forgetting is a delicate balancing act that requires memories of moderate strength so as to promote automatic sampling while still allowing for the detrimental effects of learned avoidance.

In the SAM-RI model, cue-independent forgetting in the TNT paradigm is essentially a retroactive interference effect, with recovery learning during suppression training serving to block recovery of the original target. From this perspective, the TNT paradigm is similar to traditional AB/AC retroactive interference effects (learning a new target C makes it difficult to recall the old target B). However, unlike traditional AB/AC experiments, inhibition paradigms also examine cue-independent forgetting, which is a problematic finding for traditional interference accounts. Yet, by considering two-stage recall and interference in the recovery process, interference can explain cue-independent forgetting. Although it might appear that recovery interference is an alternative to traditional interference accounts, this is not the case. Recovery interference is a mechanism that can augment traditional forms of interference, thus explaining situations of cue-independent forgetting.

One finding that seems in contradiction to a recovery interference account is Anderson and Green's (2) "no-say" condition, which revealed no forgetting effects. Participants were told to retrieve the target memory but to not say it aloud. However, this finding serves to emphasize the fact that the recovery process is not literally about performing the associated verbal production, but about identifying (recovering) the appropriate response or verbal label. If participants did as instructed in the no-say condition and attempted recovery for the target label but then withheld their overt responses, it follows from the recovery interference account that this should not produce forgetting, because no alternative completion was learned.

The SAM-RI model supposes that learned avoidance underlies no-think forgetting. In support of this claim, a learned failure to recall was reported recently with the TOT phenomenon. Warriner and Humphreys (30) found that the longer a person was kept in a TOT state in response to a cue, the more likely it was that that person reentered a TOT state at a later time in response to the same cue. One interpretation of this result is that participants successfully sampled the partial memory but found it difficult to recover the memory because of learning some alternative recovery while experiencing excessive TOT. A provocative conclusion of this work is that continued failed attempts at recovery actually do more harm than good

In summary, these results and the success of the SAM-RI model place an important cautionary note on the widely accepted assumption that cue-independent forgetting uniquely implicates an explanation based on inhibition.

Methods

Participants. Eighty-four undergraduate students participated for extra credit.

Materials. All words were selected from the University of South Florida (USF) Free Association Norms database (31).

Procedure. The study was a within-subjects 2 (initial memory strength: strong or weak) × 4 (suppression training task: recall, no-think, press-enter, or baseline) design.

There were four computerized phases to the experiment: initial learning with feedback, suppression training with feedback, original cue recall, and independent cue recall interleaved with forced-choice recognition (see Fig. 1, Fig. S1, and *SI Methods* for more detailed methods description).

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