The Search of Associative Memory with Recovery Interference (SAM-RI) memory model and its application to retrieval practice paradigms

David E. Huber
University of Massachusetts, Amherst

Tracy D. Tomlinson
University of Maryland, College Park

Yoonhee Jang
University of Montana

William J. Hopper
University of Massachusetts, Amherst

The Search of Associate Memory (SAM) memory model of Raaijmakers and Shiffrin (1981) was the first global matching model, providing a unified account of recall effects. SAM assumes that recall is a two-stage process, involving the sampling of a memory based on match to context, followed by an attempt to recover the item associated with the sampled memory. Sampling produces episodic interference because all of the matching memories compete to be sampled. In contrast, there is no interference during recovery because there is only one item associated with each sampled memory. In the 30 years since SAM was proposed, several different recall paradigms have been developed that are difficult to reconcile with global matching memory models because they produce item specific gains or losses that are independent of performance for the other studied items. However, all of these paradigms involve retrieval practice. We propose a simple and natural extension to the SAM model that makes sense of these retrieval practice paradigms. If a sampled memory involves recovery for more than one item or response, there will be interference and learning effects during the recovery process. Here we outline how the SAM model with Recovery Interference (SAM-RI) can be applied to the think/no-think paradigm, retrieval induced forgetting, and testing effects.

Corresponding Author
David Huber
Department of Psychology
Tobin Hall
135 Hicks Way
University of Massachusetts, Amherst
Amherst, MA 01003
dehuber@psych.umass.edu

I. Global Matching Memory Models

The Search of Associative Memory (SAM) model of memory (Gillund & Shiffrin, 1984; Raaijmakers & Shiffrin, 1981) was the first global matching memory model--it was the first to propose that retrieval cues (e.g., a test word plus context) are compared to the entirety of everything in one's memory. In SAM, this 'global match' defines the distribution of retrievable memories for recall and it also provides a sense of familiarity for recognition. This global match assumption has been adopted by nearly all subsequent memory models (e.g., J. R. Anderson, 1983; Dennis & Humphreys, 2001; Hintzman, 1986; Howard & Kahana, 1996; Humphreys, Bain, & Pike, 1989; Lehman & Malmberg, 2013; Mensink & Raaijmakers, 1988; Murdock, 1983; Polyn, Norman, & Kahana, 2009; Shiffrin & Steyvers, 1997). A global match seems obvious from a modern perspective. However, prior to the 1980s, most theories of long-term memory addressed the learning and unlearning of individual memories rather than interactions and interference between memories. The idea of response interference was not new to Psychology, but SAM went beyond response interference by assuming that long-term memory representations compete and interfere with each other during the retrieval process.

Despite the success of the global match assumption, several recent paradigms pose a serious challenge to this assumption. Here we propose than an auxiliary assumption of the SAM model may provide the key for addressing these challenges. Raaijmakers and Shiffrin (1980, 1981) also assumed that recall memory is a two-stage process, specifying that individual memories must be 'sampled' before their details are 'recovered'. With two stages, it is possible that memories are sampled but not recovered, similar to the tip-of-the-tongue phenomenon in which a memory is known to exist, but can't be recalled in its entirety (Brown & Mcneill, 1966). As with the global match assumption, this assumption was also adopted by most of the subsequent memory models, such as the distinction between the 'echo content' versus 'echo intensity' in MINERVA 2 (Hintzman, 1986) or the distinction between 'pattern completion' versus 'familiarity' in the complementary learning systems approach (Norman & O'Reilly, 2003). However, the recovery process isn't typically needed to explain differences between conditions--instead, it modulates recall performance across all conditions. We propose that the distinction between sampling and recovery may provide the key for explaining recently developed paradigms in which individual memories appear to be learned or unlearned in an item-specific manner (i.e., without global interference).

II. SAM Applied to Cued-Recall

We propose that learning in the recovery process can be decoupled from the learning that underlies the sampling process and we also propose that interference can occur in the recovery process when there are competing responses for a single memory. We do not present the mathematical details of these assumptions, although these can be found elsewhere (Tomlinson, Huber, Rieth, & Davelaar, 2009). Instead, our goal is to provide intuitive examples of these recovery assumptions, which produce item-specific learning and response competition. We first consider the original SAM model as applied to a standard cued-recall paradigm in which subjects study pairs of unrelated words and then attempt to recall the second word of each pair (the target) when provided with the first word (the cue) in the course of a subsequent memory test (see Figure 5.1).

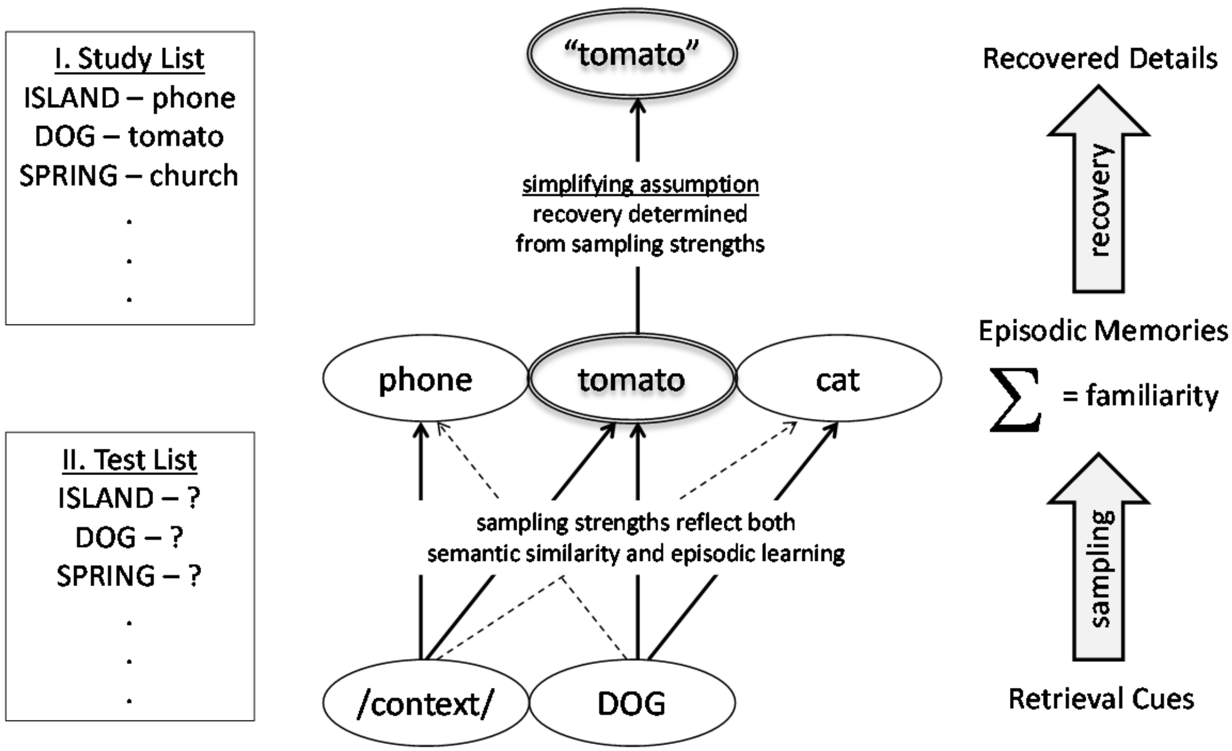

Figure 5.1. Application of the original SAM model to cued-recall. The left-hand boxes show the experimental paradigm and the connected network shows the two stages of the SAM model that first samples an episodic memory based on the retrieval cues followed by the attempt to recover the details of a sampled memory. The global match between memories and the retrieval cues defines the sampling space and this value is also used to determine familiarity for recognition judgments.

The left-hand boxes of Figure 5.1 show what the subject experiences: a study list of word pairs viewed one at time followed by a test list also viewed one at a time. The right-hand portion of the figure shows how SAM operates when attempting to recall a target word (e.g., successful recall when the subject says "tomato") based on the available retrieval cues during the test list (e.g., the word DOG plus the current context). In the SAM model, encoding of the study list increases the strength between studied words (e.g., the retrieval cues in Figure 5.1) and discrete episodic memory traces. In the figure, these episodic memory traces appear in the middle level of the three levels. The solid arrows indicate strong associations that were created during encoding of the study list. However, strong associations also exist for non-studied items based on semantic knowledge (e.g., DOG -> cat), with this explaining false memory effects in recognition (Shiffrin, Huber, & Marinelli, 1995). The dashed arrows are weak, residual associations, providing a baseline level of interference between unrelated cues and memories. The retrieval cues are used in a conjunctive fashion. In other words, the activation of each episodic memory trace is determined by multiplying the strength of association between each cue and that memory. When attempting to recall a specific target memory, that memory has to first be isolated (i.e., sampled). The sampling rule in SAM uses a Luce (1963) choice ratio to determine the probability that each memory will be sampled during a particular iteration of the memory search process. In other words, the probability of sampling a memory is the activation of that memory versus the summed activation of all memories.

Regarding the nature of sampling and recovery, Raaijmakers and Shiffrin (1981) wrote:

> …when an image is sampled, the recovery assumptions must determine the amount and type of information that can be extracted from that image. The total amount of initial activation…can be viewed as a feeling of familiarity and could conceivably be used to make a recognition judgment without further search. Detailed information is not available, however, until recovery from a sampled image occurs. Thus, in tasks such as recall, in which the details of the information are a prerequisite for a response, only the recovery from sampled images is relevant. (p. 127).

Thus, Raaijmakers and Shiffrin outlined the use of the global match (i.e., the summed activation of episodic memory traces) for both the sampling space of individual memories for recall as well as a global sense of familiarity for recognition. Subsequently, Gillund and Shiffrin (1984) provided the mathematical details for extending SAM to recognition. This quote make it clear that memories can be sampled and yet, failing recovery, the subject is unable to provide any detailed information beyond a sense of familiarity.

Because SAM uses the Luce choice rule for sampling, the absolute magnitudes of the parameters do not affect sampling. For instance, all of the associations can be made ten times larger, but this will not change the probabilities of sampling each memory. Instead, the global match assumption is only sensitive to the relative differences between sampling strengths. Nevertheless, the absolute magnitude of these parameters does affect recall performance because Raaijmakers and Shiffrin (1981) made a simplifying assumption that coupled the recovery process to the sampling process. They wrote:

> …the same retrieval strengths that determine sampling probability are used to determine the proportion of recovered elements. In general, however, these strengths might not be equal; their relationship will depend on the response requirements of the task. (p. 127).

This simplifying assumption uses the absolute magnitude of the sampling parameters to determine recall accuracy in general across all conditions. This quote also makes it clear that Raaijmakers and Shiffrin (1981) realized that other tasks and situations might decouple the sampling and recovery strengths. Here we consider the possibility that retrieval practice may selectively affect the recovery process.

III. Retrieval Practice Paradigms that Challenge Global Match Models

The vast majority of episodic memory experiments use a two-phase study/test procedure in which subjects study a list of items and then those items are tested either immediately or after a delay. However, some recent paradigms impose a retrieval practice phase prior to final test list. This retrieval practice typically occurs in the form of cued-recall and in general the effect of this retrieval practice is more robust for a final test that uses cued-recall than recognition. Of critical importance, retrieval practice appears to produce item-specific effects in certain circumstances, which challenge the assumption that retrieval is a competitive process based on a global match between retrieval cues and episodic memories. This has not gone unnoticed by proponents of global match models, and there is evidence that some of these retrieval practice effects can be attributed to processes that are compatible with global match models, such as changes in context (Camp, Pecher, & Schmidt, 2007; Jang & Huber, 2008; Jonker, Seli, & Macleod, in press; Raaijmakers & Jakab, 2013). Our goal in this chapter is not to deny or supplant ongoing efforts to explain the results of retrieval practice paradigms with the original global match models. Instead, we make the point that even if these efforts cannot fully explain the data, retrieval practice effects are nevertheless compatible with global match models provided that the recovery process of recall is decoupled from the sampling process. These paradigms may provide the impetus to go beyond the simplifying assumption made by Raaijmakers and Shiffrin (1981).

The three retrieval practice paradigms we currently consider are the testing effect (Roediger & Karpicke, 2006), the think/no-think paradigm (M. C. Anderson & Green, 2001), and retrieval induced forgetting (M. C. Anderson, Bjork, & Bjork, 1994), although this is not an exhaustive list. Below we briefly describe each of these retrieval practice paradigms followed by a qualitative demonstration that recovery learning can explain the basic phenomena. In each case, we review the literature in terms of differences between recall and recognition. Smaller and/or absent effects with recognition are to be expected if these retrieval practice effects occur via learning in the recovery process considering that familiarity does not necessitate recovery. However, we assume that some proportion of recognition judgments are made based upon recall rather than familiarity. This notion is similar to dual-process theories of recognition memory (Mandler, 1980; Tulving, 1985), although we intentionally use the term recall rather than recollection because we literally mean situations in which the subject uses the test item to recall something else about the study episode that may help them make an accurate recognition judgment. By making this assumption, the results of recognition tests in these retrieval practice paradigms can be explained through proportional blending of the standard global match recall and familiarity processes (Nobel & Huber, 1993), with the blending proportion dictated by the task demands.

IV. The Testing Effect

As first introduced by Gates (1917), the testing effect refers to the learning that takes place during a test (see Roediger & Karpicke, 2006 for a recent review). Perhaps the most intriguing aspect of this learning is that it occurs even when there is no feedback during the test. Furthermore, the benefit of testing often surpasses the benefit of additional study, particularly with delays between initial study and the final test (Carpenter & Kelly, 2012; Carpenter, Pashler, Wixted, & Vul, 2008; Karpicke & Roediger, 2008). In brief, it appears that repeatedly testing oneself protects knowledge from forgetting, serving to promote robust long-term retention. For this reason, there are obvious implications of the testing effect for education protocols (Roediger, 2013). Despite a great deal of recent interest and experimentation on the testing effect, there are, to be best of our knowledge, no formal (mathematical) process models of the testing effect. Instead, the theoretical discussion of the testing effect has focused on qualitative questions such as whether there is an advantage to retrieval practice in general or whether it is the match between the type of retrieval practice and the type of final test (i.e., transfer appropriate processing) that matters.

Providing non-parametric evidence of different forgetting rates, several studies report a crossover interaction between the practice/final-test delay and the type of practice, such that study practice is better with an immediate final test whereas test practice is better after several days (Toppino & Cohen, 2009; Wheeler, Ewers, & Buonanno, 2003). It is unclear how global matching memory models can accommodate such a markedly different forgetting rate following test practice as compared to additional study. Critically, no feedback was provided during test practice for these studies, and the results for the test practice condition likely reflect a ‘bifurcated distribution’ considering that learning from testing will only occur for items correctly recalled during test practice. In separate studies, Kornell et al. (1997), and Jang et al. (2012) highlighted this issue. Nevertheless, a bifurcated distribution does not provide a full explanation of these testing effects. First, Jang et al. still found a crossover interaction (albeit greatly diminished) when only considering items that were potentially retrievable based on an initial test. Second, although the bifurcation model proposed by Kornell et al. can describe these results while maintaining the same rate of memory strength decline for all items, it assumes that successful recall during test practice provides a huge increase in memory strength without explaining why this type of learning should be much more effective than restudy. Finally, by assuming that forgetting reflects decreases in memory strength rather than changes in interference, the bifurcation model is fundamentally at odds with global match models.

The global match models suppose that delays between study and test make it difficult to reinstate the list context and this underlies forgetting (rather than a decay of memory strength). Thus, due to retroactive and proactive interference from extra-list memories (which better match the context after a delay), the target memory is a smaller proportion of the global match, resulting in forgetting. However, it is not clear why this form of forgetting should exhibit a different temporal function (i.e.., faster forgetting) when the strengthening of a memory occurs via additional study rather than cued-recall testing. In contrast to global match interference, there appears to be some sort of item-specific advantage for the items that were successfully retrieved during test practice (i.e., these memories were made to be more easily retrievable regardless of changes in context).

We propose that successful recall during test practice leads to a selective strengthening of the recovery process. In this manner we decouple sampling and recovery such that study practice enhances sampling strengths of the studied items whereas test practice does the same, but also enhance the recovery strength of successfully recalled items (unlike SAM, simulations with SAM-RI use different parameters for sampling strength versus recovery strength). Figure 5.2 provides a specific example of this account. In this example, consider the learning from test practice that takes place by successfully recalling “tomato” when given 'DOG-?' versus additional study of 'DOG - tomato'. We hypothesize that successful recall of “tomato” increases the association between the episodic memory of 'tomato' and the overt production of the word "tomato". This makes the memory resistant to forgetting because it becomes likely that the memory will be recovered regardless of how many (i.e., immediate final test) or how few (i.e., delayed final test) times that the target memory is sampled--provided that the target memory is sampled at least once, it will be recalled. In this manner, items that are successfully recalled during test practice receive an item specific boost.

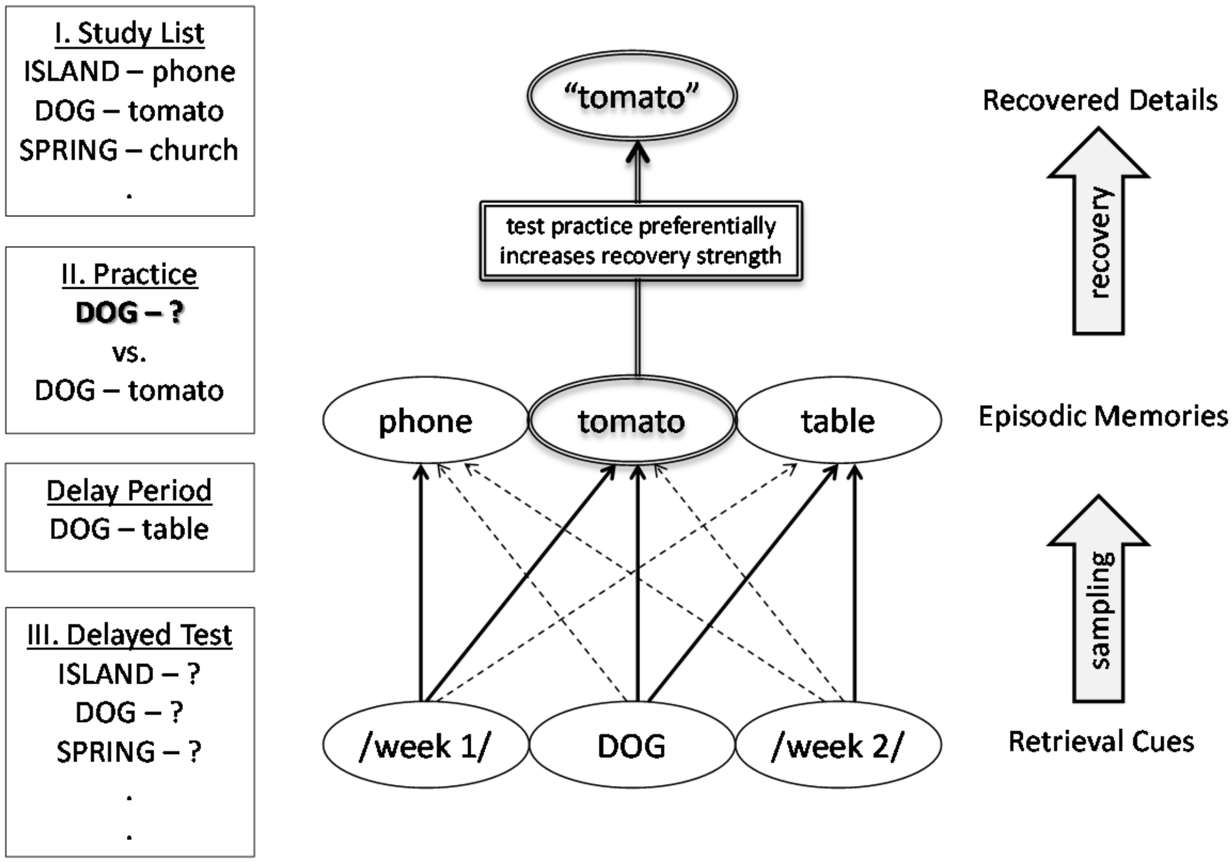

Figure 5.2. Application of the SAM-RI model to the testing effect. Testing effect experiments impose retrieval practice between initial study and a final test (shown by the box labeled 'Practice'). The key comparison is between retrieval practice in the form of additional study versus cued-recall tests. Delays between practice and a final test produce interference because the context used during the final test (e.g., /week 2/) may better match memories other than the test list. For instance, consider an episode in which a dog was seen begging at a table during the delay period. However, if test practice enhances recovery strength, then memories that were successfully recalled during test practice may be resistant to forgetting; even if the probability of sampling those memories is lower during the iterative memory search process, they only need to be sampled at least once to be successfully recovered and thus recalled.

In the example shown in the figure, the subject experiences a dog begging at the breakfast table sometime during the delay period resulting in a new association between 'DOG' and 'table'. If this episode occurred during the morning of the week 2 test, the environmental context cue used at the final test (/week 2/) will strongly match the competing memory for 'table'. This, combined with a weaker match of the week 2 context to 'tomato' (as compared to the week 1 context), reduces the probability of sampling the memory of 'tomato' for a single sampling attempt. However, because SAM allows for many sampling attempts, it may still be likely that the target memory will be sampled at least once during the memory search process, and, once sampled, it is likely to be recovered. Therefore, the recall distribution for items receiving test practice is bifurcated—ones that were successfully recalled during test practice will be easily recalled regardless of delay whereas ones that were not recalled are unlikely to be recalled at a later date.

We implemented these assumptions in SAM-RI and as expected the forgetting rate following test practice is less than the forgetting rate following restudy (Hopper & Huber, 2014). Nonetheless, we failed to produce the crossover interaction between study/test practice and retention interval in our initial simulation. Instead, successful test practice not only produced better performance after a delay, but also better performance for an immediate final test. However, upon closer examination, we realized that we had failed to implement a critical assumption of the original SAM model. Raaijmakers and Shiffrin (1981) made the assumption that the success or failure of the recovery process for individual items is deterministically related to the retrieval cues. They wrote:

> ...the outcome second and subsequent recovery attempts will match the outcome of the first recovery attempt. In addition, if the context cue and any other word cue together do not lead to recovery of Image i, then it assumed that any subsequent recovery attempt for Image i with context cue only will also fail. Thus a new independent recovery chance occurs whenever the probe set contains a new cue. (p. 96)

This assumption says that if you find yourself stuck with a tip-of-the-tongue failure to recover a sampled memory, you are destined to continue to fail in any additional recovery attempts until context changes (or a different item cue is used). As applied to the testing effect, we assumed that an immediate final test uses the same context cues that were used during test practice. Thus, the items that were not recalled during test practice cannot be recalled during an immediate final test. With a delay, a change in context provides a relative advantage to the test practice condition as compared to restudy because the previously non-recalled items from the first session of the experiment are now given a new chance at recovery. Another way to put this is that there is a short-term cost to test practice by committing oneself to non-recoverability for a subset of the items. By including this original assumption of the SAM model, we found that the SAM-RI model could produce a highly accurate account of the testing effect crossover interaction.

This account predicts that test practice will result in less forgetting if test practice involves recovery *and* performance on the final test relies on recovery. The studies reviewed above used recall during both test practice and final recall and consistently found less forgetting following test practice. Whether this also holds true with recognition test practice and/or a recognition final test will depend on whether task demands encourage subjects to use recall to inform their recognition judgments (i.e., judging a word as studied because the episodic circumstances of study are recalled). More specifically, our account predicts that previous recall practice will primarily affect recognition judgments that are based on recall (aka recollection) as compared to familiarity-based recognition judgments. This has been confirmed for an immediate final test (Chan & McDermott, 2007), but this has not yet been examined as a function of delay.

V. Think / No-think

Practice recalling a memory can make that memory resistant to forgetting. But what happens if someone practices *not* recalling a memory? Similar to the notion of Freudian repressed memories, the think/no-think (TNT) paradigm of Anderson and Green (2001) examines the unlearning of memories. Like the other retrieval practice paradigms, the TNT paradigm includes an initial study list and a final cued recall list. Furthermore, one of the conditions is a testing effect condition because subjects practice recalling the target word in response to the cue word (the 'think' condition). In another condition, subjects practice memory suppression by spending four seconds blocking the target word from their mind in response to the cue word (the 'no-think' condition). This manipulation is within-subjects. Following initial study, the subject memorizes the cue words for the no-think condition. During the practice phase, cue words appear one at a time, and subjects either attempt to recall the target word or they suppress the target word as appropriate to each cue word (see Figure 5.3).

Final test performance in the no-think condition is lower than the control condition, suggesting that these memories have been unlearned. Furthermore, this memory deficit appears to be item specific, as revealed by an independent probe of the no-think memories. This is done by presenting subjects with the name of a category that includes the target word, plus the first letter of the target word (e.g., 'FOOD - t'). For instance, the subject studies 'DOG - tomato' then practices suppression of 'tomato' whenever 'DOG' appears. After this suppression training, they are given the cue 'FOOD - t' and asked to use this to recall a category member that appeared on the original study list. However, even though this independent cue is unrelated to the original cue word, performance is still lower in the no-think condition as compared to the control condition. Such a finding cannot be explained by a global match sampling process because the independent probe should avoid any interference from competing memories learned during suppression training.

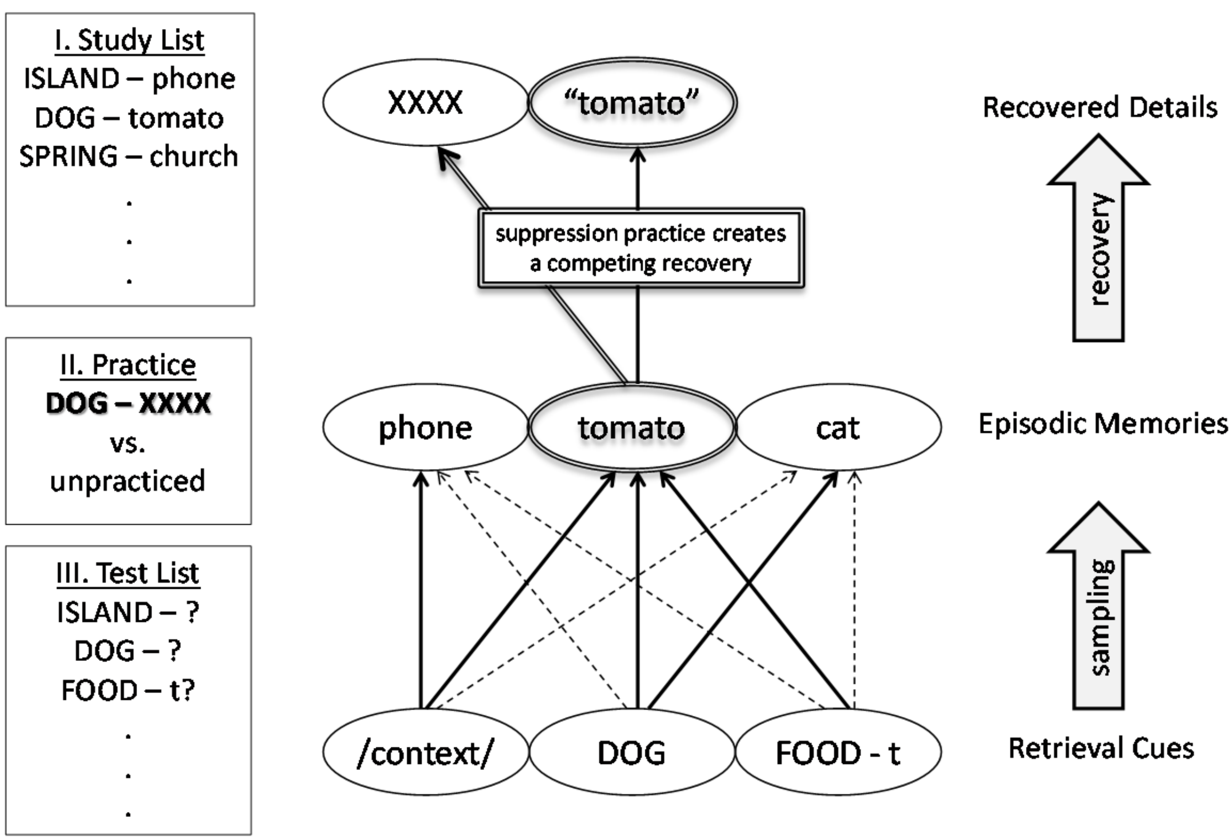

Figure 5.3. Application of the SAM-RI model to the think / no-think (TNT) paradigm (Tomlinson, et al., 2009). A single episodic memory may have more than one potentially recovered detail. This results in interference during the recovery process. In the TNT paradigm, practice suppressing a target word (e.g., blocking 'tomato' from one's mind when given the cue 'DOG') is assumed to cause a newly learned association between the original memory and the recovered detail to do something else (XXXX). Because this interference is in the recovery process, it causes forgetting even when memory is probed with a cue that is independent of learning (i.e., 'FOOD - t?').

Results with independent probes are small and of questionable reliability (e.g., Bulevich, Roediger, Balota, & Butler, 2006; Raaijmakers & Jakab, 2013). However, our goal in this chapter is not to debate whether the independent probe results hold true. Instead, we consider whether these results necessarily contradict global match models. To address this question, we developed the Search of Associative Memory model with Recovery Interference (SAM-RI) model as reported and tested by Tomlinson, Huber, Rieth, and Davelaar (2009). This model is similar to the proposed testing effect model in that it decouples sampling and recovery. However, this model goes a step farther by allowing that a single sampled episodic memory can be associated with more than one recovered detail. During suppression training, we assume that the original memory (e.g., DOG – tomato) is sampled and any additional learning serves to update the memory trace (as in the REM model of Shiffrin & Steyvers, 1997). This updating causes the memory to now be associated with a different behavioral response (e.g., whatever it is that the subject elects to do or think when asked to suppress the memory: XXXX) and this response becomes a competing potential recovery to recovery of the target word. Thus, rather than unlearning memories during suppression training, the subject has learned to do something else when that memory comes to mind.

The SAM-RI model made several key predictions as applied to the TNT paradigm. The most important of these was that successful suppression training merely requires that the subject learn to recover a different response, rather than requiring active memory suppression. To test this claim, we ran an experiment that included the no-think condition as well as a 'press-enter' condition in which subjects learned to press the enter key as quickly as possible in response to some of the cue words. As predicted, both the no-think condition and the press-enter condition revealed memory deficits as compared to the baseline condition. Furthermore, both of these conditions produced forgetting regardless of whether final test used the original cue or an independent probe. Another key prediction was that these forgetting effects should be unique to the recovery process. Thus, a final test that only involves sampling (i.e., familiarity) should not reveal any forgetting. As mentioned above, recognition testing can be used to assess familiarity, but only in circumstances that minimize the role of recall-based recognition judgments. To minimize the role of recall-based recognition, we used forced-choice testing (Holdstock et al., 2002). As predicted, we did not observe any forgetting for either the no-think or press-enter conditions for this recognition test. The data of these conditions, as well as a strength manipulation, were well fit by a relatively simple implementation of the SAM-RI model, demonstrating that the results of the TNT paradigm do not necessarily imply that memories are unlearned or suppressed.

Aside from our study, we are aware of only one other study that examined recognition in the TNT paradigm, although that study reached a different conclusion, finding recognition deficits in the no-think condition (Hart & Schooler, 2012). There are several differences between our study and Hart and Schooler's study, but the key difference may be that Hart and Schooler used single item old/new testing whereas we used forced-choice testing. The SAM-RI model does not necessarily predict the absence of no-think forgetting with recognition, but rather it predicts the absence of no-think forgetting for familiarity-based recognition. Our study used forced-choice testing to reduce the contribution of recall to recognition responses whereas the subjects in Hart and Schooler's study may have used recall to guide their recognition responses.

VI1. Retrieval Induced Forgetting

Like the TNT paradigm, the Retrieval Induced Forgetting (RIF) paradigm was developed to examine inhibition processes in memory (M. C. Anderson, et al., 1994); as with the TNT paradigm, an inhibition account of RIF proposes that inhibition of unwanted memories during retrieval practice has lasting consequences, resulting in item-specific unlearning of the inhibited memories. In light of SAM-RI's success explaining the TNT results, we consider whether this recovery interference model can also explain the results from the RIF paradigm[1].

As with the other retrieval practice paradigms, the first phase of the RIF paradigm presents subjects with word pairs to study and the final phase uses cued-recall. However, unlike the other paradigms, the words in RIF are categorical. For instance, during the study list, the subject might study a list of food items, each one being paired with the category name (see Figure 5.4). During retrieval practice, some, but not all of these category members are practiced. This is achieved by presenting the first letter of each category memory that should be recalled (e.g., 'FOOD - c?'). Memory for these Retrieval Practiced category members (the 'RP+' condition) improves but memory for the category members that did not receive retrieval practice (the 'RP-' condition) is worse than for a control condition that did not include any retrieval practice. As with the TNT paradigm, an independent probe condition also finds forgetting for the RP- items, demonstrating that this memory deficit is item specific. In this case, the independent probe is achieved by including category members that belong to more than one of the categories used in the experiment (e.g., 'tomato' is both a 'FOOD' but also something that is 'RED'). For an independent probe test, this alternative category cue is presented during the final test (e.g., 'RED - t'), but forgetting is still found.

[1] The application of SAM-RI to RIF was first reported by Tomlinson (2009)

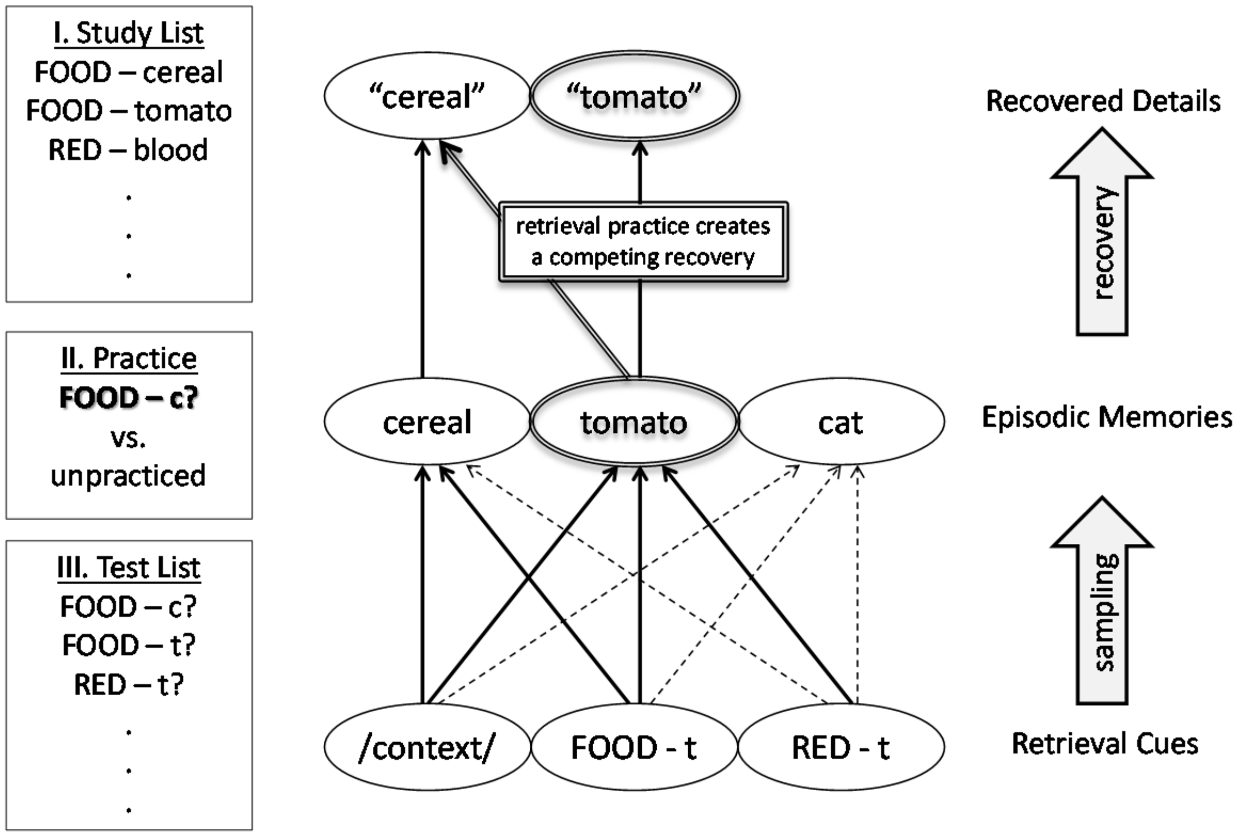

Figure 5.4. Application of the SAM-RI model to the Retrieval Induced Forgetting (RIF) paradigm. In the RIF paradigm, practice recalling some members of a category (e.g., 'FOOD - c?') causes forgetting for unpracticed members of that category. If all food memories are activated during retrieval practice, including unpracticed items, this will result in newly learned associations between sampled unpracticed items (e.g., memory for 'tomato') and the practiced response (e.g., "cereal"). Even if the unpracticed item is cued in an independent manner (e.g., 'RED - t?'), this competing recovery will cause interference.

There are mixed results with independent probe forgetting in the RIF paradigm: some researchers report independent probe forgetting (M. C. Anderson & Spellman, 1995; Aslan, Bauml, & Pastotter, 2007; Saunders & MacLeod, 2006), while others fail to find this effect (Camp, et al., 2007; Camp, Pecher, Schmidt, & Zeelenberg, 2009; Perfect et al., 2004; Williams & Zacks, 2001). Again, our goal is not to resolve this debate, but rather to demonstrate that if and when it occurs, independent probe forgetting is nevertheless compatible with a global match interference account of memory.

Figure 5.4 outlines the SAM-RI model as applied to the RIF paradigm. Similar to global match recognition memory in which a target word activates not only that word, but all words on the study list, we assume that retrieval cue (e.g., 'FOOD - c?') activates a sampling set of memories that includes all of the food items from the original study list. However, the subject knows that the correct answer begins with 'c' rather than 't'. Thus, even if the memory for 'tomato' is sampled, the subject can use semantic knowledge to generate the correct answer of "cereal". To the extent that this occurs, production of the answer "cereal" becomes associated with the memory for 'tomato', creating a competing recovery for the RP- items. Simply put, retrieval practice causes new associations between the unpracticed items and the practiced items. Thus, regardless of how the unpracticed items are cued, there is interference (e.g., if the memory for 'tomato' is sampled from the cue 'RED – t?', it is difficult to produce "tomato" owing to the newly learned competing association between that memory and the practiced production of the word "cereal").

This explanation is not intended to supplant other interference-based accounts. For instance, Jonker et al. (2013) propose that RIF reflects context change, with retrieval practice causing an association between the practiced category and the most recent context, which in turn causes a deficit for the RP- items considering that those items were only encoded with the original study context. Similar to the current proposal, Verde (2013) simulated RIF results with a variant of the SAM model. By assuming that different situations cause more or less encoding of context features (rather than item features) during retrieval practice, SAM was able to explain why RP+ benefits can occur regardless of whether there are or are not RP- deficits. This follows because context features affect sampling (interference for RP- items) whereas item features affect recovery (item specific RP+ benefits). However, neither of these interference accounts of RIF can explain forgetting with independent probes. Nonetheless, if independent probe forgetting exists, it can be explained by SAM-RI as outlined above.

Aside from independent probe forgetting, the other key test of the SAM-RI model is a final test with recognition rather than recall. More specifically, SAM-RI predicts that RIF forgetting effects should in general be smaller for recognition depending on the degree to which recognition responses are familiarity-based rather than recall-based. There are several studies that used recognition tests in the RIF paradigm, with mixed results. Some researchers have found RP- forgetting in terms of recognition accuracy (Hicks & Starns, 2004; Spitzer & Bauml, 2009), while others do not (Koutstaal, Schacter, Johnson, & Galluccio, 1999; Veling & van Knippenberg, 2004). However, Veling and van Knippenberg did find an effect of recognition latency for RP- items. This has been verified by Verde and Perfect (2011), who found RP- forgetting with self-paced recognition but not with speeded recognition. This result is consistent with the SAM-RI model. More specifically, on some trials, the subject may attempt to recall the original study details to better inform their recognition responses and it is this aspect of recognition judgments that will be more strongly affected by retrieval practice. Because recall takes longer than the familiarity response, speeded recognition responses are predicted to be less sensitive to retrieval practice effects.

VIII. Conclusions

Global match memory models have explained a wide variety of recognition and recall results over the last 30 years. However, recently developed retrieval practice paradigms pose a serious challenge to the interference view of forgetting. There are ongoing efforts to address these challenges within the original framework of the global match models, although it is not easy to explain item specific effects. Here we propose a natural extension of the global match models that produces item specific effects—the SAM-RI model decouples the memory strengths that underlie the sampling process from the memory strengths that underlie the recovery of specific details.

The SAM-RI model affords additional flexibility and includes additional free parameters (i.e., separate parameters for sampling and recovery learning). Nevertheless, novel predictions follow from this account. For instance, as applied to the testing effect, this account predicts that while recovery learning may appear to protect memories from forgetting when measured in terms of recall accuracy, the effect of forgetting will be made apparent in terms of longer search times. As applied to the TNT paradigm, this account predicted that memory suppression only depends on learning to do something else other than recall the indicated memory and this result was confirmed (Tomlinson, et al., 2009). As applied to RIF, this account predicts that the forgetting effect critically hinges of the sampling of the unpracticed items during retrieval practice. In addition to task-specific predictions such as these, we have highlighted predictions regarding recall-based recognition for each of these paradigms—to the extent that recall is used to inform recognition judgments during retrieval practice and/or a final test, these item specific effects can occur with recognition.

References

Anderson, J. R. (1983). A Spreading Activation Theory of Memory. *Journal of Verbal Learning and Verbal Behavior, 22*(3), 261-295.

Anderson, M. C., Bjork, R. A., & Bjork, E. L. (1994). Remembering Can Cause Forgetting - Retrieval Dynamics in Long-Term-Memory. *Journal of Experimental Psychology-Learning Memory and Cognition, 20*(5), 1063-1087.

Anderson, M. C., & Green, C. (2001). Suppressing unwanted memories by executive control. *Nature, 410*(6826), 366-369.

Anderson, M. C., & Spellman, B. A. (1995). On the Status of Inhibitory Mechanisms in Cognition - Memory Retrieval as a Model Case. *Psychological Review, 102*(1), 68-100.

Aslan, A., Bauml, K. H., & Pastotter, B. (2007). No inhibitory deficit in older adults' episodic memory. *Psychological Science, 18*(1), 72-78.

Brown, R., & Mcneill, D. (1966). Tip of Tongue Phenomenon. *Journal of Verbal Learning and Verbal Behavior, 5*(4), 325-327.

Bulevich, J. B., Roediger, H. L., Balota, D. A., & Butler, A. C. (2006). Failures to find suppression of episodic memories in the think/no-think paradigm. *Memory & Cognition, 34*(8), 1569-1577.

Camp, G., Pecher, D., & Schmidt, H. G. (2007). No retrieval-induced forgetting using item-specific independent cues: evidence against a general inhibitory account. *Journal of Experimental Psychology-Learning Memory and Cognition, 33*(5), 950-958.

Camp, G., Pecher, D., Schmidt, H. G., & Zeelenberg, R. (2009). Are Independent Probes Truly Independent? *Journal of Experimental Psychology-Learning Memory and Cognition, 35*(4), 934-942.

Carpenter, S. K., & Kelly, J. W. (2012). Tests enhance retention and transfer of spatial learning. *Psychonomic Bulletin & Review, 19*(3), 443-448.

Carpenter, S. K., Pashler, H., Wixted, J. T., & Vul, E. (2008). The effects of tests on learning and forgetting. *Memory & Cognition, 36*(2), 438-448.

Chan, J. C. K., & McDermott, K. B. (2007). The testing effect in recognition memory: A dual process account. *Journal of Experimental Psychology-Learning Memory and Cognition, 33*(2), 431-437.

Dennis, S., & Humphreys, M. S. (2001). A context noise model of episodic word recognition. *Psychological Review, 108*(2), 452-478.

Enns, J. T., & DiLollo, V. (1997). Object substitution: A new form of masking in unattended visual locations. *Psychological Science, 8*(2), 135-139. doi: DOI 10.1111/j.1467-9280.1997.tb00696.x

Gates, A. I. (1917). Recitation as a factor in memorizing. *Archives of Psychology, 40*, 104.

Gillund, G., & Shiffrin, R. M. (1984). A Retrieval Model for Both Recognition and Recall. *Psychological Review, 91*(1), 1-67.

Hart, R. E., & Schooler, J. W. (2012). Suppression of novel stimuli: Changes in accessibility of suppressed nonverbalizable shapes. *Consciousness and Cognition, 21*(3), 1541-1546.

Hicks, J. L., & Starns, J. J. (2004). Retrieval-induced forgetting occurs in tests of item recognition. *Psychonomic Bulletin & Review, 11*(1), 125-130.

Hintzman, D. L. (1986). Schema Abstraction in a Multiple-Trace Memory Model. *Psychological Review, 93*(4), 411-428.

Holdstock, J. S., Mayes, A. R., Roberts, N., Cezayirli, E., Isaac, C. L., O'Reilly, R. C., & Norman, K. A. (2002). Under what conditions is recognition spared relative to recall after selective hippocampal damage in humans? *Hippocampus, 12*(3), 341-351.

Hopper, W. J., & Huber, D. E. (2014). *A Recovery Learning Account of the Testing Effect*. Paper presented at the Context and Episodic Memory Symposium, Philadelphia, PA.

Howard, M., & Kahana, M. J. (1996). Mathematical model of free recall memory. *Journal of Mathematical Psychology, 40*(4), 349-350.

Humphreys, M. S., Bain, J. D., & Pike, R. (1989). Different Ways to Cue a Coherent Memory System - a Theory for Episodic, Semantic, and Procedural Tasks. *Psychological Review, 96*(2), 208-233.

Jang, Y., & Huber, D. E. (2008). Context retrieval and context change in free recall: Recalling from long-term memory drives list isolation. *Journal of Experimental Psychology-Learning Memory and Cognition, 34*(1), 112-127.

Jang, Y., Wixted, J. T., Pecher, D., Zeelenberg, R., & Huber, D. E. (2012). Decomposing the interaction between retention interval and study/test practice: The role of retrievability. *Quarterly Journal of Experimental Psychology, 65*(5), 962-975. doi: Doi 10.1080/17470218.2011.638079

Jonker, T. R., Seli, P., & MacLeod, C. M. (2013). Putting Retrieval-Induced Forgetting in Context: An Inhibition-Free, Context-Based Account. *Psychological Review, 120*(4), 852-872. doi: Doi 10.1037/A0034246

Jonker, T. R., Seli, P., & Macleod, C. M. (in press). Putting retrieval-induced forgetting in context: An inhibition-free, context-based account. *Psychological Review*.

Karpicke, J. D., & Roediger, H. L. (2008). The critical importance of retrieval for learning. *Science, 319*(5865), 966-968.

Koutstaal, W., Schacter, D. L., Johnson, M. K., & Galluccio, L. (1999). Facilitation and impairment of event memory produced by photograph review. *Memory & Cognition, 27*(3), 478-493.

Lehman, M., & Malmberg, K. J. (2013). A Buffer Model of Memory Encoding and Temporal Correlations in Retrieval. *Psychological Review, 120*(1), 155-189. doi: Doi 10.1037/A0030851

Luce, R. D. (1963). Detection and recognition. In R. D. Luce, R. E. Bush & E. Galanter (Eds.), *Handbook of mathematical psychology* (pp. 103-187). New York,: Wiley.

Mandler, G. (1980). Recognizing - the Judgment of Previous Occurrence. *Psychological Review, 87*(3), 252-271. doi: Doi 10.1037/0033-295x.87.3.252

Mensink, G. J., & Raaijmakers, J. G. W. (1988). A Model for Interference and Forgetting. *Psychological Review, 95*(4), 434-455.

Murdock, B. B. (1983). A Distributed Memory Model for Serial-Order Information. *Psychological Review, 90*(4), 316-338.

Nobel, P. A., & Huber, D. E. (1993). *Modeling forced-choice associative recognition through a hybrid of global recognition and cued-recall*. Paper presented at the Proceedings of the 15th Annual Conference of the Cognitive Science Society.

Norman, K. A., & O'Reilly, R. C. (2003). Modeling hippocampal and neocortical contributions to recognition memory: A complementary-learning-systems approach. *Psychological Review, 110*(4), 611-646.

Perfect, T. J., Stark, L. J., Tree, J. J., Moulin, C. J. A., Ahmed, L., & Hutter, R. (2004). Transfer appropriate forgetting: The cue-dependent nature of retrieval-induced forgetting. *Journal of Memory and Language, 51*(3), 399-417.

Polyn, S. M., Norman, K. A., & Kahana, M. J. (2009). A Context Maintenance and Retrieval Model of Organizational Processes in Free Recall. *Psychological Review, 116*(1), 129-156.

Raaijmakers, J. G. W., & Jakab, E. (2013). Rethinking inhibition theory: On the problematic status of the inhibition theory for forgetting. *Journal of Memory and Language, 68*(2), 98-122.

Raaijmakers, J. G. W., & Shiffrin, R. M. (1980). SAM: a theory of probabilistic search of associative memory *The psychology of learning and motivations* (Vol. 14, pp. 207-262). New York: Academic Press.

Raaijmakers, J. G. W., & Shiffrin, R. M. (1981). Search of Associative Memory. *Psychological Review, 88*(2), 93-134.

Roediger, H. L. (2013). Applying Cognitive Psychology to Education: Translational Educational Science. *Psychological Science in the Public Interest, 14*(1), 1-3. doi: Doi 10.1177/1529100612454415

Roediger, H. L., & Karpicke, J. D. (2006). The Power of Testing Memory Basic Research and Implications for Educational Practice. *Perspectives on Psychological Science, 1*(3), 181-210.

Saunders, J., & MacLeod, M. D. (2006). Can inhibition resolve retrieval competition through the control of spreading activation? *Memory & Cognition, 34*(2), 307-322.

Shiffrin, R. M., Huber, D. E., & Marinelli, K. (1995). Effects of Category Length and Strength on Familiarity in Recognition. *Journal of Experimental Psychology-Learning Memory and Cognition, 21*(2), 267-287.

Shiffrin, R. M., & Steyvers, M. (1997). A model for recognition memory: REM - retrieving effectively from memory. *Psychonomic Bulletin & Review, 4*, 145-166.

Spitzer, B., & Bauml, K. H. (2009). Retrieval-Induced Forgetting in a Category Recognition Task. *Journal of Experimental Psychology-Learning Memory and Cognition, 35*(1), 286-291.

Tomlinson, T. D. (2009). *Learning to Forget: An Interference Theory of Cue-Independent Forgetting*. Unpublished Doctoral Dissertation. Psychology Department. University of Maryland, College Park.

Tomlinson, T. D., Huber, D. E., Rieth, C. A., & Davelaar, E. J. (2009). An interference account of cue-independent forgetting in the no-think paradigm. *Proceedings of the National Academy of Sciences of the United States of America, 106*(37), 15588-15593. doi: DOI 10.1073/pnas.0813370106

Toppino, T. C., & Cohen, M. S. (2009). The Testing Effect and the Retention Interval Questions and Answers. *Experimental Psychology, 56*(4), 252-257. doi: Doi 10.1027/1618-3169.56.4.252

Tulving, E. (1985). Memory and Consciousness. *Canadian Psychology-Psychologie Canadienne, 26*(1), 1-12.

Veling, H., & van Knippenberg, A. (2004). Remembering can cause inhibition: Retrieval-induced inhibition as cue independent process. *Journal of Experimental Psychology-Learning Memory and Cognition, 30*(2), 315-318.

Verde, M. F. (2013). Retrieval-Induced Forgetting in Recall: Competitor Interference Revisited. *Journal of Experimental Psychology-Learning Memory and Cognition, 39*(5), 1433-1448.
Verde, M. F., & Perfect, T. J. (2011). Retrieval-induced forgetting in recognition is absent under time pressure. *Psychonomic Bulletin & Review, 18*(6), 1166-1171.
Wheeler, M., Ewers, M., & Buonanno, J. (2003). Different rates of forgetting following study versus test trials. *Memory, 11*(6), 571-580.
Williams, C. C., & Zacks, R. T. (2001). Is retrieval-induced forgetting an inhibitory process? *American Journal of Psychology, 114*(3), 329-354.