Putting Measurements of Retrieval-Induced Forgetting to the Test

BY
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THESIS
Submitted as partial fulfillment of the requirements
for the degree of Master of Arts in Psychology
in the Graduate College of the
University of Illinois at Chicago, 2012

Chicago, Illinois

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    Jim Pellegrino
For Aubrey,

who has never forgotten me.
Acknowledgements

Conducting research often feels like being on an island, where other topics can seem far and detached from our own, but the poet John Donne (albeit, in a vastly different context) expressed the idea that no one is an island—so I cannot, in good conscience, separate my work from the people I wish to thank now and those I regret I cannot fit onto one page.

For my advisor Ben Storm, and his guidance over the past three years. Ben has challenged me to become a better speaker, writer, and researcher, and I am grateful for the time he has given me. I wish him well at his new career at UC Santa Cruz. With Ben, I also want to thank my committee, Stellan Ohlsson and Jim Pellegrino for their comments during my proposal and initial data, as well as their generosity in regards to the flagrantly bad Stroop Task software used in my study.

For my colleagues Rebecca Koppel and Tara Jobe, who provided valuable feedback during the various phases and forms my thesis has taken. I appreciate being able to piggy-back on their IRB forms through the years. I’m going to miss our lab and I wish them very best. For Kate Brill and Jared Ramsberg (my most excellent officemates), Joanna Bovee (for her PECOLSUS mastery), Ed Sargis, Nic McCarley, Brendan McCarthy (mastermind of a hilarious music video on statistics), Lara Mercurio (for her kindness and curiosity of the world), and Patrick Butler (with whom I often commiserated during late nights in BSB). I also wish to thank Sarah Johnson, for game club and propelling me into grad school.

For Mom and Dad, because I could not have asked for better or more loving parents. For my brother, Patrick, for being an inspiration to push myself in such worthy pursuits as academia and pinochle, the game of kings (or is it aces?) Finally, I thank my wife, Aubrey for being together with me through this journey and always being mindful of me every step of the way.
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<th>Acronym</th>
<th>Description</th>
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<tr>
<td>ADHD</td>
<td>Attention Deficit / Hyperactivity Disorder</td>
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<td>ANOVA</td>
<td>Analysis of Variance</td>
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<td>DLPFC</td>
<td>Dorsolateral prefrontal cortex</td>
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<td>ISI</td>
<td>Inter-stimulus Interval</td>
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<td>RAT</td>
<td>Remote Associates Task</td>
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<td>RIF</td>
<td>Retrieval-induced Forgetting</td>
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<td>RP</td>
<td>Retrieval Practice</td>
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<td>Rp+</td>
<td>Practiced item</td>
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<td>Rp-</td>
<td>Non-practiced and related item</td>
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<tr>
<td>NRp</td>
<td>Non-practiced and unrelated item, or baseline item</td>
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<tr>
<td>NRp+</td>
<td>Baseline item for Rp+ items</td>
</tr>
<tr>
<td>NRp-</td>
<td>Baseline item Rp- items</td>
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<td>RT</td>
<td>Reaction Time</td>
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<tr>
<td>SSD</td>
<td>Stop-signal Delay</td>
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<td>SSRT</td>
<td>Stop-signal Reaction Time</td>
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SUMMARY

Retrieval-induced forgetting (RIF) is a consequence of retrieval that produces forgetting of other, previously learned information. Presently, researchers disagree on whether the phenomenon is inhibitory in nature, and numerous studies have been conducted to test this notion. However, category-cued tests, a common test design, may be inappropriate for testing the inhibitory account of RIF due to interference effects. Instead, researchers should use tests that reduce the role of interference in RIF at test, such as category-plus-stem-cued tests.

Individual RIF performance on each of these test types were compared to performance on an established measure of response inhibition (i.e. stop-signal reaction time). Results showed that only participants in the category-plus-stem-cued test exhibited inhibitory control performance consistent with RIF performance: Participants with high inhibitory control also showed greater RIF. However, participants in the category-cued condition showed the opposite relationship: Failure to inhibit predicted greater RIF performance. Results suggest that RIF is attributable to both inhibitory and non-inhibitory sources, that tests that reduce interference may better capture inhibition-based RIF, and that researchers must be careful to employ test designs appropriate for research objectives.
I. INTRODUCTION

It is wholly remarkable that cognitive research has been able to take a phenomenon as insufferable as forgetting, and frame it as an essential component of memory. While common sense may suggest that forgetting indicates a flawed system of cognition, there are still circumstances we all encounter where forgetting would be practical, if not necessary. For instance, we are often asked to change an online password, sometimes requiring different characters. When we later need to remember the new password, the old password can interfere, making it difficult to successfully login. Forgetting our old password, therefore, would facilitate access to our current password. In this case, our old password represents active, but contextually inappropriate information that interferes during retrieval. In the face of such interference, successful recall is a twofold process: it involves more than knowing the target information, but also the active forgetting of competitive information that interferes during retrieval.

One phenomenon consistent with this process of resolving competition in memory is retrieval-induced forgetting (Anderson, Bjork, & Bjork, 1994). Simply put, it describes the forgetting of other information as a consequence of retrieval. Retrieval-induced forgetting (RIF) is typically demonstrated in a three-phase experiment called the retrieval-practice paradigm. In an initial study phase, a large set of category-exemplar pairs (e.g. among many others, METAL – iron; METAL – copper; TREE – birch) are shown and studied by participants. In subsequent retrieval practice, participants attempt to recall half of the items from half of the categories through a category and a two-letter stem cue (e.g. METAL – ir for iron; but neither copper nor birch would be practiced). This creates three types of critical items: Items receiving retrieval practice (denoted as Rp+), items categorically related to practiced items (denoted as Rp-), and
unrelated baseline items (denoted as NRp). At final test, all studied items are tested. Expectedly, Rp+ items (e.g. iron) are best recalled due to the benefits of prior retrieval. More notably, compared to NRp items (e.g. birch), Rp- items (e.g. copper) consistently show lower recall. This difference in recall between NRp items and Rp- items is called RIF. The effect is robust and has been replicated with a wide range of stimuli, including homographs (Johnson & Anderson, 2004), visuospatial information (Ciranni & Shimamura, 1999), autobiographical memories (Barnier, Hung, & Conway, 2004) and eyewitness accounts (Shaw, Bjork, & Handal, 1995; MacLeod, 2002; Garcia-Bajos, Migueles, & Anderson, 2009), demonstrating that RIF generalizes to a wide variety of contexts.

Retrieval-induced forgetting is generally argued to be best explained by one of two accounts: inhibition and interference. The forgetting of information in memory has often been accounted for through interference processes owing to the heightened accessibility of other, associated items (e.g. Rundus, 1973; Raaijmakers & Shiffrin, 1981; Mensink & Raaijmakers, 1988). Interference accounts generally posit that RIF is a consequence of events occurring during final test. Namely, participants recall fewer Rp- items compared to NRp items because Rp+ items that have the benefit of retrieval practice block access to related Rp- items. Interference theory posits that retrieval practice does not directly suppress access to Rp- items; rather, it is the high accessibility of practiced items that prevents or blocks retrieval of related items. Explanations based on interference theory are passive in that they do not require executive processes to stifle retrieval of related items. Interference-based accounts are supported by several researchers (e.g. Williams & Zacks, 2001; Butler, Williams, & Zacks, 2001; MacLeod, Dodd, Sheard, Wilson, & Bibi, 2003; Camp, Pecher, & Schmidt, 2005).
Alternatively, others have argued that inhibition better accounts for RIF in that access to Rp- items is suppressed by an inhibitory process as a result of competing with Rp+ items during retrieval practice (e.g. Anderson et al., 1994; Anderson, 2003; Bäuml, Zellner, & Vilimek, 2005; Storm, Bjork, Bjork, & Nestojko, 2006). For instance, when participants see an item such as METAL – *ir* during retrieval practice, the category cue may activate many associated items. The degree to which related, but inappropriate associates become accessible serves as a source of competition that antagonizes retrieval of an appropriate response (i.e., iron). To resolve this competition, an inhibitory process intervenes to suppress accessibility to such items. Subsequently, this suppression facilitates retrieval of an appropriate item and prevents retrieval of contextually inappropriate items. This reduction in accessibility is consistent with the definition of inhibition proposed by Bjork (1989): That inhibition is an active, direct form of suppression that serves to reduce access to one or several responses.

There are a number of other properties that distinguish inhibitory accounts from interference accounts of RIF. First, prior literature suggests that RIF is consistently produced by mechanisms occurring with retrieval practice, but does not result from restudying of previous material (e.g. Ciranni & Shimamura, 1999; Bäuml & Hartinger, 2002). This finding characterizes inhibition-based RIF as *recall specific*, meaning that it requires retrieval processes in order for previously studied items to compete in memory. A second assumption is that forgetting is *strength independent*; the degree to which Rp+ items are strengthened is not predictive of the resulting RIF of Rp- items (e.g. Anderson, Bjork, & Bjork, 2000). Most interference accounts, on the other hand, would predict more RIF when practiced items are strengthened.
A third assumption posits RIF as *competition dependent*. The more competition (or interference) that arises from studied items during retrieval practice, the more inhibition is required to suppress those inappropriate responses. Some previous studies have provided evidence supporting competition dependence through the taxonomic frequencies of items (Anderson, Bjork, & Bjork, 1994), by directing participants to remember or forget studied items (Storm, Bjork, & Bjork, 2007), or through using dominant and subordinate homograph meanings (Shivde & Anderson, 2001, Experiments 1 & 3). Whereas interference accounts such as *blocking* predict RIF based on the strengthening and accessibility of practiced items, competition dependence in inhibition-based RIF relies on the accessibility of previously studied items and how strongly they interfere during retrieval-practice.

A. *Final Test Design in Retrieval-induced Forgetting*

Since the inception of retrieval-induced forgetting studies, multiple final test types have been used to measure RIF. Notably, while there are qualitative differences in the nature of these final tests, the results of each have been used to discuss theoretical accounts. In fact, the decision to use a given type of final test has been somewhat atheoretical and indiscriminate. As I will later discuss, there are reasons to suspect that final tests of RIF are not equally effective in allowing for theoretical conclusions to be drawn from their results.

The two measures used most often in the RIF literature are category-cued and category-plus-stem-cued tests. Category-cued recall was a mode of testing first used by Anderson et al., 1994 (Experiment 1), and involves the presentation of a single, previously studied category that has been associated with multiple studied items. In their experiment, participants were given a period of 30 s for each category to recall as many items as possible. Retrieval-induced forgetting
was measured by comparing the average proportion of Rp- items recalled compared to baseline NRp items.

While category-cued recall has enjoyed frequent use among researchers, there are several reasons to suspect that this method produces RIF partially based on interference, and therefore does not purely reflect inhibition during retrieval. A key issue is that category-cued recall tests are sensitive to various sources of strength-based interference. For instance, by allowing participants to recall items in any order in a given category, forgetting of competitors could be produced simply through output interference (Rundus, 1973). Retrieving the strongest items initially would impair recall of nonpracticed items within the same category (i.e. Rp- items). In fact, Anderson et al. (1994) demonstrated that when using category cues, the output position of practiced items at test was substantially earlier than unpracticed items (for comparable effects in part-set cuing, see Roediger, Stellon, & Tulving, 1977). Another property of category-cued tests is that the category cue lacks specificity. For instance, presenting the category FRUIT alone could produce spreading activation of a number of previously studied items at once, thus causing associative interference during initial search. With respect to theory development, these interference effects are particularly troubling knowing that researchers have used category-cued recall tests to suggest inhibitory accounts of RIF are either 1) restricted in scope due to failures to reproduce the effect (e.g. Williams & Zacks, 2001) or 2) that RIF is not adequately explained by the inhibitory account (e.g. Perfect, Moulin, Conway, North, Jones, & James, 2002; Perfect, Stark, Tree, Moulin, Ahmed, & Hutter, 2004; Jakab & Raaijmakers, 2009).

Finally, populations with known inhibitory deficits continue to show normal levels of RIF when output interference is not controlled (e.g. Conway & Fthenaki, 2003; Soriano, Jiménez, Román, & Bajo, 2009). This is unexpected, as these populations should suffer from less
forgetting due to diminished inhibitory capacity. Storm and White (2010) demonstrated that college students with attention deficit hyperactivity disorder (ADHD) showed normal amounts of forgetting when output interference was not controlled, but when output interference was controlled, students with ADHD showed no RIF. Failure to control for output interference may account for similar findings of RIF in other populations with inhibitory deficits such as Alzheimer’s disease (Moulin, Perfect, Conway, North, Jones, & James, 2002) and young children (Zellner & Bäuml, 2005).

In accounts of RIF, category-cued tests are the subject of a more general problem referred to as the *correlated costs and benefits of inhibition* (Anderson & Levy, 2007): that forgetting based on inhibition during retrieval practice and forgetting based on interference at test are inversely related to one another. The reason for this relationship is because the need to resolve competition arises during both retrieval practice and final test—while we might retrieve *orange* from *FRUIT* - or and forget the competitor *apple* during retrieval practice, at final test, *orange* may need to be forgotten to retrieve *apple*. Individuals with high inhibitory control are better able to resolve competition during retrieval practice by inhibiting Rp- items, but this also means that they resolve competition more efficiently during test by inhibiting Rp+ items to recall Rp- items. Conversely, individuals with poorer inhibitory control are worse at resolving competition during retrieval practice and suffer more from interference at test. This means that they fail to inhibit Rp- items during retrieval practice, but are unable to inhibit them during final test. To the extent that interference can be reduced at final test, the more certain we can be that differences in RIF can be explained by differences in inhibition during retrieval practice. However, because both interference- and inhibition-based effects of RIF could be present in category-cued tests, such tests do not address the *correlated costs and benefits* problem.
Taken together, category-cued recall tests fall short in their ability to gauge inhibition-based RIF (Anderson & Levy 2007; Storm, 2011). Consequently, alternative test designs have been employed to address the problem of output interference. The category-plus-stem-cued test adds only a minor change, specifically by providing a single-letter stem in addition to the category cue for each studied item at test. In addition, participants are tested on individual items (e.g. TOOL – h for “hammer”), rather than an entire category. Items are typically shown in blocked randomization, consisting of one item from each category (e.g. Anderson, Bjork, & Bjork, 2000; Bäuml & Kuhbahnder, 2007). Blocks can be set such that a set of Rp- items are tested before Rp+ items (e.g. Anderson et al., 1994, Experiment 3). In doing so, the primary advantage is that the obtained RIF can no longer be the product of interference effects owing to the output of practiced items (e.g. Anderson et al., 1994; Anderson, Bjork, & Bjork, 2000; Bajo, Gomez-Ariza, Fernandez, & Marful, 2006; Storm, Bjork, Bjork, & Nestojko, 2006; Bäuml & Kuhbandner, 2007; Storm & White, 2010; Goodmon & Anderson, 2011). That is, RIF measured through tests that reduce the role of interference at test should more accurately reflect RIF caused by inhibition.

B. Measurements of General Inhibitory Processes

One outstanding question in the investigation of RIF deals with characterizing how the processes underlying inhibition-based RIF are related to general inhibitory control. Characterizing the nature of inhibition presently accounting for RIF relative to other measures of inhibition would help develop the concept of inhibition in the larger picture of executive control. Executive control is somewhat ill-defined in the current literature, but it is generally understood to be the set of mechanisms that manage the operation of numerous cognitive processes (Miyake, Friedman, Emerson, Witzki, & Howerter, 2000). Some processes that are thought to be
governed by executive functioning are the shifting of mental sets, monitoring and updating of memory representations, and most relevant to the current study, the inhibition of prepotent responses. Although there are reasons to believe that category-cued-plus-stem tests are necessary to support an inhibitory account of RIF, few studies have investigated whether the inhibitory control resulting from RIF can be predicted by independent and established measures of the ability to overcome competition from a prepotent response (e.g. Aslan and Bäuml, 2011, for an example using working memory capacity).

1. **Stroop task.** One measure that could be used to assess each test of RIF is the Stroop task. As a well-established measure of inhibitory control, it has been used extensively to measure inhibitory control over a dominant response, namely that when presented with a word, reading the written word is a prepotent response (for an extensive review of the task, see MacLeod, 1991). Participants are typically presented with three phrases: One where they identify colors based on non-verbal stimuli, one where they identify font colors using verbal stimuli, and one where they identify font colors on words with mismatched color names. Evidence favoring Stroop performance as a measure of inhibition include differences in performance based on speed instructions and intertrial intervals affecting response competition (Neill and Westberry, 1987), differences in special populations with inhibitory deficits such as negative schizophrenia compared to controls (Laplante & Everett, 1992), and differences in naming speed based manipulations of color-consistent and inconsistent items (Glaser & Glaser, 1982).

The Stroop effect is optimally explained using a model of response competition (e.g. Keele, 1972). Both word and color information are thought to be processed in parallel up until the point where motor processes are required. Processes relevant to the task are executed and irrelevant stimuli dimensions must be prevented from overtaking the overt response. Naturally,
there is no conflict when stimuli dimensions are congruent or do not interfere with each other (e.g. when color name and font color are the same). If, however, incongruent stimuli dimensions need to be named, the irrelevant motor process may arrive before the correct one does. Behavioral difficulty in the task and differences in RT between congruent and incongruent trials is explained by difficulty in suppressing the first motor processes that become active so as to select the second, appropriate response.

Several versions of the Stroop task have been developed (see MacLeod, 1991, for a review). The current study will employ a version used by Kane and Engle (2003, Experiment 3). Across several of their experiments, participants were shown individual items. However, one group of participants was only shown color names that were incongruent with their font color, as opposed to being shown incongruent items along with neutral items (e.g. a random string of letters such as WXZT) and color-congruent items. There are two main reasons why using this particular version is optimal: First, performance on congruent and neutral items does not require participants to overcome a prepotent response, and performance on those trials is less critical than performance on incongruent trials in regard to the current research question. Secondly, and perhaps more importantly, Kane and Engle considered that mixing congruent and incongruent trials could introduce a new demand on the task that may cause difficulty when examining individual differences. In addition to inhibiting prepotent responses, participants who use different strategies to respond correctly would also have more difficulty in maintaining the goal of the task. Specifically, some participants may rely on the fact that on congruent trials, they are able to simply read the word to respond correctly. This strategy is inappropriate for incongruent trials, however, and must be shifted to reporting the text color. By introducing a 0% congruent
condition, Kane and Engle argued that differences in Stroop performance better reflect inhibitory control rather than differences in goal maintenance.

Whether RIF performance correlates with Stroop performance is an open question. Anderson (2005) has discussed how RIF may reflect general inhibitory processes that act to override prepotent responses. Furthermore, recent studies have demonstrated evidence that participants who show more RIF are more resistant to interference (e.g. Aslan & Bauml, 2011), coinciding with the inhibitory account. Results from Storm and Angello (2010) supported this notion based on the relationship between RIF performance and subsequent performance on a remote associates task (RAT). Participants who showed more RIF were more resistant to fixation on the RAT task compared to participants who showed less RIF. This effect became more dramatic the longer the participants were engaged in the RAT task. Because RIF appears to be predictive of participants’ ability to overcome interference, and that the Stroop task requires participants to overcome a dominant response (i.e. reading a written word) to respond correctly (i.e. reporting the color of text), individuals with high RIF performance should be faster at responding during the 0% congruent Stroop Task. This correlation should be strongest when the task measuring RIF controls for interference-based sources of forgetting by using a category-plus-stem-cued test.

2. Stop-signal task. The stop-signal task (for a review, see Logan & Cowan, 1984) is a second measure that could be used to assess inhibitory capacity, where participants must quickly withhold or execute a response based on presented stimuli. A single trial consists of three stages: fixation, stimulus presentation, and an inter-stimulus interval (ISI). Logan & Cowan (1984) showed a fixation point, followed by stimulus. On 75% of the trials, participants engaged in the primary task where participants identified the stimulus, and were asked to respond as quickly as
possible after stimulus onset. However, on the other 25% of the trials, a tone referred to as a stop-signal would sound, indicating that the participant should not respond. The difficulty of the task was manipulated by adjusting the stop signal to occur at different delays after stimulus onset. Participants’ ability to withhold a response was measured on the stop-signal trials through an estimate called stop-signal reaction time (SSRT). One major finding relevant to the current proposal is that the probability of responding to a stop signal increases with stop-signal delay (e.g. Logan, 1982; Logan, Cowan, & Davis, 1984).

SSRTs have been used heavily in defining inhibitory deficiencies in clinical groups, such as children with ADHD (e.g. Nigg, 2001; see Oosterlaan, Logan, & Sergeant, 1998 for a review). In addition, SSRTs have also shown to be consistent with individual performance on other inhibitory measures such as the flanker and Stroop tasks (Verbruggen, Liefooghe, & Vandierendonck, 2004). Performance in the stop-signal task is often modeled under a horse-race model (Logan & Cowan, 1984), where a “go” process, initiated by stimulus onset and a “stop” process, initiated by the stop-signal, compete for activation. For example, the go process is likely to “win” the race when there is a large delay between stimulus onset and stop signal, and the participant will erroneously respond on that trial. However, when the stop signal is given earlier, the stop process is more likely to be active and correctly prevent a response. The speed at which an individual can restrain their response is estimated using the probability of withholding a response on stop-signal trials, and their RTs during the primary task, resulting in the SSRT estimate (see Logan & Cowan, 1984 for discussion of the formula).

The current study will use a computerized version of the stop-signal task using software called STOP-IT (Verbruggen, Logan, & Stevens, 2008). The program is similar to the original task with one primary exception. STOP-IT automatically adjusts the difficulty for withholding a
response based on performance on any given stop-signal trial: when participants fail to withhold their response, the task becomes easier, and when participants correctly withhold their response, the task becomes more difficult. This allows the program to individually estimate the speed at which participants are able to withhold their response. Participants who fail on stop-signal trials roughly 50% of the time generally yield accurate SSRT estimates, because this indicates that a threshold has been reached in their ability to withhold a response. SSRTs have been shown to be highly reliable using a sufficient number of trials per participant; 95% confidence intervals using at least 20 stop-signal trials per participant were less than 20 ms, and when using at least 50 stop-signal trials, confidence intervals were less than 10 ms (Band, van der Molen, & Logan, 2003). The current study will use 64 stop-signal trials to estimate individual SSRT.

The stop-signal task measures the ability to withhold a response when it is inappropriate, and may seem to measure something different than RIF. However, Anderson (2003, 2005) argues that the inhibitory process that drives RIF may also account for many forms of response suppression. Much like retrieval-induced forgetting, the stop-signal task requires participants to resolve competition; in stop signal, participants must overcome a prepotent response to respond on a given trial in order to successfully stop their response. Additional evidence for this function of inhibition in relation to RIF is supported by neuroimaging work. Decreased demands on cognitive control reveal the neural processing benefits of forgetting. Kuhl, Dudukovic, Kahn, and Wagner (2007) demonstrated that the prefrontal areas thought to be devoted to detection (anterior cingulated cortex) and resolving competition (dorsolateral and ventrolateral prefrontal cortex) are activated during retrieval practice. More interestingly, activation of these areas systematically decreases with additional retrieval practice, and these reductions across retrieval-practice repetitions predicted the resulting RIF for individuals. This supports the notion that both
RIF and stop-signal performance are functions of executive control. Namely, they are both forms of response override, where situational demands require the need to stop a prepotent response. Inhibitory-based retrieval induced forgetting requires forgetting of active, previously studied items in order to recall item during retrieval practice. Stop-signal performance requires participants to withhold their response that they provide on a majority of the trials. Inhibition is thought to guide both of these processes that require the need to overcome a strong, contextually inappropriate response.

In the current study, I intended to test the degree to which category cued and category-plus-stem cued tests relate to measures of cognitive control using the stop-signal task and Stroop task. Cognitive control tasks that measure the ability to withhold a response should reflect individual differences in retrieval-induced forgetting. Specifically, in the category-plus-stem-cued condition, the better cognitive control an individual has, the more RIF they should demonstrate (see Figure 1). Conversely, RIF obtained from measures that are sensitive to interference such as category-cued tests should not be predicted well by individual differences in cognitive control, suggesting that this interference-based RIF does not reflect differences in inhibitory control during retrieval practice (see Figure 1). Although it is not yet clear how processes underlying interference and inhibition interact with one another, one possibility is that they counteract one another. Alternatively, interference may be additive to the extent that the effects of inhibition-based forgetting are effectively overshadowed by interference-based forgetting. We predict this neutralization will occur when a category-cued test is used, where both inhibition during retrieval-practice and output interference at test affect recall during the test.

II. METHODS

A. Participants
A total of 133 participants were run in the study. On the stop-signal task, eight participants (three in category-cued, five in category-plus-stem-cued conditions) were removed because they significantly deviated from 50% success on stop-signal trials. Because their SSRTs could not be reliably calculated based on their performance, all eight participants’ were dropped from the study. Two participants’ were dropped because their SSRT performance fell four standard deviations below the mean SSRT. One participant was dropped due to RIF performance three standard deviations above the mean RIF score. Finally, one participant was dropped due to their own report of drowsiness and an inability to maintain attention during the study.

After removing these subjects, data from 121 participants were used in the final analysis (63 in category-cued, 58 in category-plus-stem-cued).

B. Design

The current study contained three phases. First, participants completed the retrieval-practice paradigm, where we obtained RIF performance. Second, participants completed the Stroop task, where we measured response latency. Finally, participants completed the stop-signal task, where individual stop-signal reaction time was estimated. In the retrieval-practice paradigm, item type was manipulated within subjects. Item type refers to the status of a category-exemplar pair based on retrieval-practice. Across participants, category-exemplar pairs were equally likely to be practiced (Rp+), unpracticed within a practiced category (Rp-) or a baseline item (NRp+ or NRp-). Separate baselines were created to ensure that the relevant RIF comparison (Rp- vs. NRp-) would not be a product of particular item characteristics.-). The type of final test used during the retrieval-practice task (category-cued vs. category-plus-stem-cued)
was manipulated between subjects, and the retrieval-practice status was manipulated within subjects. No manipulations were used for the Stroop or stop-signal tasks.

C. Retrieval-practice Paradigm

1. Materials. Category-exemplar pairs (see Appendix A) were used as study material. Ten categories consisting of eight exemplars each were chosen. Exemplars were obtained from categorical norms by Van Overschelde, Rawson, and Dunlosky (2002). Exemplars were chosen to be of medium taxonomic frequency according to these norms, and were ranked an average of 4.5 according to their output position. One study list was constructed, and the presentation order was determined by blocked randomization. Each block of eight items consisted of one item from each category, and the study list was comprised of ten blocks. Items from the same category were never presented consecutively.

Two lists for retrieval practice were constructed, where half of the items from half of the categories (16 items) underwent three rounds of retrieval practice. Presentation order during retrieval practice was also determined by blocked randomization, where a block consisted of four items, one from each of four practiced categories for a given list. One round of retrieval practice consisted of three blocks. Items in each of the three rounds of retrieval practice were presented in a different block-randomized order.

Finally, one test list was constructed for the category-cued condition, where all eight category cues are presented in a random order. However, two test lists were constructed for the category-plus-stem condition, ensuring that each list required participant to retrieve Rp- and NRp- items before Rp+ or NRp+ items, based on which practice list they received. Test lists in the category-plus-stem condition were also presented using blocked randomization in a similar
manner as the study phase, where a block contained one item from each category. However, the
test list and the study list were in a different order.

2. Procedure. Participants studied 80 items in total. Participants in either category-cued or stem-cued recall test conditions were tested on all 80 items (see Appendix B for instructions). The paradigm consisted of three phases: A study phase, a retrieval-practice phase, and a test phase (see Figure 4). All participants completed the same study phase. In the initial study phase, participants were instructed to remember the items shown, and were more specifically instructed to do so by considering the relationship between the category and its exemplar (e.g. “Think about how a hammer is a type of tool”). Items were shown one at a time for 3s. During retrieval practice, participants were shown a category and two-letter stem cue representing a previously studied item. Participants were given 5 s to say aloud a response based on items they previously studied. An experimenter wrote down all given responses.

Participants were tested on all studied items in one of two conditions. Participants in the category-cue condition were shown one of the categories (e.g. METAL), and asked to say aloud all studied exemplars they were able to recall from that category. Category cues were shown for a total of 30 s. In the category-plus-stem cue condition, participants were shown a category along with a one-letter stem specific to a studied item in that category (e.g. METAL – i for iron). Items were shown for 5 s, and participants’ verbal responses were recorded (see Appendix B for instructions). Average recall for Rp+, NRp+, Rp-, and NRp- items were calculated. Retrieval-induced forgetting was calculated by subtracting the average recall for Rp- items from NRp- items. Because lowered recall of Rp- items compared to baseline indicates the presence of RIF, this means that higher RIF scores are more positive, whereas lower RIF scores (i.e. facilitation, or an absence of RIF) are more negative. For participants in the category-cued condition, the
average recall position of Rp+ and Rp- items for participants in the category-cued condition was also measured to assess individual differences in output interference.

D. Stroop Task

1. Materials. Stroop task items were primarily designed according the 0% congruent condition Stroop task used by Kane and Engle (2003, Experiment 2), and were run through a computer program called Inquisit 3.0 (Millisecond Software, 2011). Four color names and font colors were used: red, blue, green, and black. A total of 84 critical stimulus trials were included in the task, where all trials included color names incongruent with their font color. Ten initial practice trials used neutral stimuli (i.e. letter strings such as “YWXQ”) in each of the different colors. (see Figure 3) The 84 trials following practice were critical trials. Trials were split into seven randomized blocks of 12 items, such that every incongruent font color-name combination is shown exactly once in a given block. Font colors and color names were never presented consecutively.

2. Procedure. Participants first completed a practice task using neutral letter strings, and were instructed to identify the color of the word presented as quickly and accurately as possible. Then, participants were introduced to the critical trials (see Appendix B for instructions). In both tasks, participants selected the color name using one of four keys on the keyboard (“d” for red, “f” for green, “j” for blue, and “k” for black), and were further instructed to place their index and middle fingers of each hand on the appropriate keys in preparation.

If the participant correctly selected the color for a trial, the screen went blank for 200ms and proceeds to the next trial. If the participant incorrectly selected a color for a trial, the screen displayed an “X” in the middle of the screen for 400ms before it was blanked for 200ms and then
moved to the next trial. While making a selection, each trial was self-timed, and latency was recorded for every trial. Stroop task performance was measured by overall latency as well as average latency within each block of 12 trials.

E. Stop-signal task

1. Procedure. After completing the Stroop task, participants were given the stop-signal task (see Figure 5). The task was run on computer software called STOP-IT (Verbruggen, Logan, & Stevens, 2008). The program is a shape judgment task, where participants must discriminate between a square and a circle. Most of the trials (75%) require the participants to respond as quickly as possible by pressing an appropriate keyboard key to identify the shape. However, on the rest of the trials (25%), participants receive a brief auditory signal soon after stimulus onset to indicate the need to withhold a response on that trial. By default, the signal occurs 250 ms after stimulus onset. When inhibition is successful on these trials, the task is made more difficult by increasing the stop-signal delay (SSD) by 50 ms. When inhibition is unsuccessful, however, the task is made easier by decreasing the SSD by 50 ms. In this manner, participants are likely to succeed or fail at withholding a response on a stop-signal trial for roughly half of the trials. This measurement provides a threshold for an individual’s ability to override a prepotent response. Participants who perform better at the task can correctly withhold a response when the SSD is longer. Their stop-signal reaction time, or the estimated time it takes for the “stop” process to be activated, is therefore estimated to be faster.

In the current study, participants were told they will see either see a circle or a square and that after the stimulus has been shown, they will need to identify the displayed shape using one of two keys. These keys were the “Z” and “J” keys, which are covered with a square and a circle
respectively. Participants were also informed that on trials when a signal is present, they should withhold their response. The experiment consisted of two phases: a practice phase of 32 trials, and an experimental phase which included four blocks of 64 trials. After the end of a block, participants waited 10 s before beginning the next block. During this interval, participants received information about their performance for the last block, including the number of incorrect responses on no-signal trials, the number of missed responses on no-signal trials, the mean RT on no-signal trials, and the percentage of correct suppressed trials (see Appendix B for instructions).

Several dependent measures were collected using STOP-IT, but the primary measurement for the current study was stop-signal reaction time (SSRT). SSRTs are estimated by subtracting the average SSD for a participant from the mean RT on stop-signal trials (Logan et al., 1997). Estimated SSRTs will be used to evaluate inhibitory capacity, where lower SSRTs indicate better inhibitory capacity and higher SSRTs represent poorer inhibitory capacity.

III. RESULTS

A. Retrieval Practice Paradigm

1. Retrieval Practice. On average, participants recalled 81% of the items. Participants in the category-cued condition were just as successful at recalling studied items (M = 81.75%, SD = 15.32%) as participants in the category-plus-stem-cued condition (M = 81.25%, SD = 13.23%), t(1,119) = .71, p = .475.

2. Final Test. Two analyses of variance were conducted to assess practice effects and RIF effects in the final recall test for the two testing conditions (see Table I). To assess whether retrieval-practice enhanced recall for Rp+ items was apparent, a 2 (Item type: Rp+, NRp+) x 2
(Testing condition: category-cued, category-plus-stem-cued) ANOVA was conducted. The results of the ANOVA confirmed a main effect of item type where Rp+ items were recalled better than their NRp+ controls, $F(1,119) = 270.56, p < .001$, $\eta^2 = 0.695$, and a main effect of testing condition where participants in the category-cued condition recalled more items overall than participants in the category-plus-stem-cued condition, $F(1,119) = 5.93; p = .016$, $\eta^2 = .047$. However, no interaction was observed $F(1,119) = .02, p = .882$, suggesting no differences in the practice effects between the category-cued and category-plus-stem-cued condition (Ms = .29 and .28, respectively).

Critically, it was important to confirm that RIF effects were present in both testing conditions through a similar 2 (Item type: Rp-, NRp-) x 2 (Testing Condition) ANOVA. Analyses revealed a main effect of Item Type, $F(1,119) = 57.21, p < .001$, $\eta^2 = .325$, supporting the notion that Rp- items were indeed recalled less well than their baseline NRp- items. There was also a main effect of testing condition, $F(1,119) = 8.334, p < .005$, $\eta^2 = .065$. No interaction was observed between Item Type and Testing Condition, $F(1,119) = 2.74, p = .101$, suggesting no differences in the amount of RIF between the category-cued and category-plus-stem-cued condition (Ms = .12 and .07 respectively). To ensure that RIF effects were robust across test conditions, planned contrasts between Rp- and NRp- items were conducted accordingly. Results confirmed that that RIF effects for category-cued and category-plus-stem-cued tests were robust (Cohen’s $d$s of .53 and .51, respectively).

**B. Stroop Task**

A critical error was encountered in latency data. Across participants, latencies for some trials were recorded as negative values, as though a response was recorded prior to the
presentation of a given word. One explanation about why this occurred may be due to errant participant behavior. However, this seems unlikely as participants were given clear instructions on when to respond, as well as the fact that researchers were present in the room while participants completed the Stroop task. A second explanation could be a fundamental error in the program itself; for instance, the program may have accepted input when it was inappropriate, or, for a given trial, the program began recording response latency later than the beginning of stimulus onset. In any case, the data is not usable because it does not provide an adequate individual differences measure of inhibitory control, and will not be used in subsequent analyses.

C. Stop-signal Task

Between both testing groups, participants withheld their response on stop-signal trials roughly half the time (M = 50.43%, SD = 5.18%) and the average SSRT was 272.69 ms. To ensure that were no chance group differences that could specifically affect performance, we compared their SSRT performance, and confirmed that the groups did not differ from each other in this respect, t(1, 119 = 0.57, ns). The category-cued and category-plus-stem-cued groups were also compared in terms of the distribution of SSRT performance (see Table II). Levene’s test showed no significant differences in the variances of SSRT performance between the two testing conditions, F(1,118) = .054, p = .816.

D. Regression Analyses

A hierarchical regression (see Table III) was carried out to assess whether SSRTs predicted RIF performance differently depending on type of test participants received. The first analysis used three individual difference factors (SSRT, Testing condition, and the SSRT x Testing Condition interaction) to predict RIF performance. Individual SSRTs were appropriately
centered prior to analysis. The first step included both SSRT and Testing Condition as predictors, and did not produce a significant model, $F(2, 118) = 1.36, p = .261, \Delta r^2 = .023$. However, including the interaction term in the second step did produce a significant model, $F(3, 117) = 4.60, p = .004, \Delta r^2 = .083, r^2 = .105$. In this model the SSRT x Test Condition interaction was a significant predictor, and accounted for more than 8% of the variance in RIF performance. In addition, Test Condition was a marginally significant predictor of RIF performance.

Correlations between RIF and SSRT between category-cued and category-plus-stem-cued final tests further demonstrate this point (see Figure 2). On category-cued tests, there was a positive correlation ($r = 0.29, t(1,61) = 2.37, p = .011$) indicating that participants who showed more RIF at final test also had higher SSRTs. Conversely, on category-plus-stem-cued tests, there was a negative correlation ($r = -0.30, t(1,56) = 2.35, p = .011$) indicating that participants who showed more RIF had lower SSRTs. Using Fisher’s z-transforming procedure, the two correlation coefficients were confirmed to be different from each other, $z = -3.26, p = .001$.

Another hierarchical regression was carried out to examine degree to which RIF was affected by practice effects, that is, the degree to which Rp+ items were recalled better than NRp+ items as a result of retrieval practice. To perform this analysis, a difference score between average recall for Rp+ and NRp+ items was calculated for each participant. This predictor will be referred to as the Practice Effect. Prior to analysis, practice effects were appropriately centered. The first step of the regression (see Table IV) included three factors (Test Condition, SSRT, and Practice Effect) as predictors of RIF, and did not yield a significant model of RIF, $F(3, 117) = 1.71, p = .169, \Delta r^2 = .042$. To examine whether the relationship between practice effects differed by the type of test participants took, we included a Practice Effect x Test Condition interaction term, and added this factor in the second step of the regression. This step
also failed to produce a significant model of RIF, $F(4,116) = 1.28$, $p = .281$, $\Delta r^2 < .000$, $r^2 = .042$. Finally, the SSRT x Test Condition interaction was added in the third step of the regression, which produced a significant model $F(5,115) = 3.10$, $p = .012$, $\Delta r^2 = .076$, $r^2 = .119$, confirming that the only significant predictor in the model of RIF was the differences in SSRTs as a function of test condition.

**IV. DISCUSSION**

The aim of the current study was to examine whether retrieval-induced forgetting is differentially related to other measures of inhibitory control depending on whether output interference is controlled for in the test phase of the retrieval practice-paradigm. Previous studies have repeatedly demonstrated that RIF occurs regardless of what test type is used, but few have tested whether RIF derived from different test types is distinguishable based on inhibition- and interference-based accounts. The present study replicates such RIF effects using both test types (e.g. Anderson, Bjork, & Bjork, 1994, Storm & White, 2010; Aslan, Bäuml, & Pastotter, 2007), but more importantly, individual differences in RIF were best explained by SSRTs as a function of RIF test participants took, revealing that our inhibition measure predicted different relationships across the two test conditions of RIF. Participants in the category-plus-stem-cued condition demonstrated a negative relationship between SSRTs and RIF, meaning that participants who were better able to withhold a response on stop-signal trials (i.e. faster SSRTs) showed more RIF. Conversely, RIF from category-cued tests showed a positive relationship with SSRTs, demonstrating that participants who were less able to withhold their response (i.e. slower SSRTs) showed more RIF.

In the category-cued condition, RIF is difficult to make sense of from an inhibitory standpoint. Given that response suppression is thought to underlie RIF (Anderson, 2003; 2005)
and SSRTs (Logan & Cowan, 1984), why would participants who are less able to withhold responses also have high RIF? In other words, why would someone who has poor response suppression during stop-signal trials also have good response suppression during RIF? One possibility is that, although inhibition may have occurred, category-cued tests may have masked the effects of inhibition. Instead, the resulting forgetting is better accounted by individual differences in susceptibility to interference at test. This explanation is supported in two ways: First, category-cued tests are sensitive to both output and strength-based associative interference due to the lack of specificity in the cue. Second, participants with poor response suppression could also have experienced difficulty in resisting retrieval of prepotent responses. It is unsurprising, therefore, that these same participants suffered more interference during final test, producing higher RIF performance compared to individuals with better response suppression.

The converse relationships observed with category-cued and category-plus-stem-cued relationships to response suppression are consistent with research on groups with inhibitory deficits. Using category-cued tests, patients with schizophrenia (Soriano et al., 2009) or ADHD (Storm & White, 2010) have comparable RIF effects to control groups, yet these groups do not show RIF using tests that reduce interference during final test. The current findings show that both category-cued and category-plus-stem-cued tests both show significant RIF effects, but based on its relationship to SSRTs, it is clear that category-cued tests do not reflect inhibition, but rather, show that the lack of inhibition drives differences in RIF.

That RIF based on category-cued tests may not accurately reflect inhibitory processes has important consequences, specifically how prior work using such tests should be understood. For instance, Jakab and Raaijmakers (2009) manipulated serial position of items during their initial study phase in order to test the competition-dependent assumption of the inhibitory account of
RIF. According to the account, RIF should have been highest for initially studied items, and less for later studied items. However, in using a category-cued test, Jakab and Raaijmakers observed no differences in the amount of RIF across serial position, and took this as evidence against the inhibitory account. Based on the current study, this conclusion seems premature, because the resulting RIF is confounded by both inhibition at retrieval practice and interference at final test. Furthermore, the fact that no differences in RIF were found across serial position is consistent with some interference accounts such as blocking, where strengthening of Rp+ would introduce broad interference effects at test on Rp- items. There are several other studies using category-cued recall whose conclusions on inhibition would be similarly suspect (e.g. Williams & Zacks, 2001; Perfect, Moulin, Conway, North, Jones, & James, 2002; Perfect, Stark, Tree, Moulin, Ahmed, & Hutter, 2004).

In the category-plus-stem-cued condition, the pattern of RIF was consistent with the inhibition account. Participants who were better able to withhold their responses during the stop-signal task also showed higher RIF. From the standpoint that response suppression underlies SSRTs, the current findings suggest that RIF from category-plus-stem-cued tests can also be explained through the same mechanism. This finding adds to a growing literature suggesting that RIF is not only a useful measurement for understanding the control of memory, but also for executive control. Inhibitory processes underlying RIF are also thought to be responsible for the suppression of undesirable behaviors and contextually-irrelevant stimuli in the environment (Levy & Anderson, 2002). This supposition is substantiated with neurological findings that activation in areas of the dorsolateral prefrontal cortex (DLPFC) during memory suppression in retrieval practice is comparable to processes involved in stopping dominant motor responses (Anderson, Ochsner, Kuhl, Cooper, Robertson, Gabrieli, et al., 2004). Furthermore, tasks that
divide attention or otherwise disrupt executive functioning during retrieval practice also reduces the amount of RIF (Román, Soriano, Gómez-Ariz, & Bajo, 2009). Furthermore, individuals with greater ability to engage in goal-directed activity should also be able to discard task-irrelevant information. Consistent with this supposition, Aslan and Bäuml (2011) demonstrated that individuals with higher levels of working memory capacity also showed higher levels of RIF compared to individuals with lower working memory capacity.

The current results also emphasize the importance of the correlated costs and benefits problem when interpreting why RIF occurs. Several authors have addressed the problem that the presence of RIF by itself is no indication of whether the effect is inhibitory in nature (e.g. Anderson & Levy, 2007; Soriano et al., 2009). For instance, poor inhibitory control could produce difficulties in suppressing competitors during retrieval practice and exacerbate the effects of blocking-based interference at test. If tests that are sensitive to interference are employed, such as category-cued tests, the effects of inhibition and interference are confounded, and the underlying mechanism driving RIF effects is not definitive. This problem is highlighted in category-cued condition, where participants who showed better response suppression on the stop-signal task did not show consistent forgetting of competitors. In fact, these participants were actually more likely to remember competitors. However, when using procedures that reduced the role of interference-based RIF through a category-plus-stem-cued test, we found that better response suppression on the stop-signal task predicted more forgetting of competitors.

Category-plus-stem-cued RIF, based on a measure of response suppression, suggests that inhibition during retrieval practice, not interference at test, best explains RIF occurring in category-plus-stem-cued tests. However, a more direct way to rule out interference-based explanations would be to examine whether strengthening of practiced information accounted for
the observed RIF effects across test conditions. Individual differences in retrieval practice success are one measurement that could reflect such strengthening, but there were no differences in performance between conditions. Another measure of strengthening could be reflected in degree to which practiced items benefitted from retrieval practice at test compared to baseline items. To see whether these practice effects accounted for the resulting RIF across the two groups, a hierarchical regression procedure was used (Table I), which confirmed neither practice effects nor their interaction with test type accounted for individual differences in RIF. Given that interference accounts (e.g. Camp, Pecher, & Schmidt, 2007; Jakab & Raaijmakers, 2009) rely upon the assumption that RIF extends from strengthening of practiced items, it is difficult to map such accounts onto the present findings.

The current study does not support the idea that RIF is entirely explained by an inhibition- or interference-based account, and whether all occurrences of RIF are best explained by one account or another is perhaps a question wrongly asked. Instead, the present findings are consistent with the idea that RIF can be produced by both sources (e.g. Verde, 2012). This is an important distinction, because retrieval practice occurring before category-cued testing should produce inhibitory-based RIF in addition to RIF based on interference effects at test. However, because the resulting RIF in category-cued tests did not appear consistent with performance on an established inhibitory task (stop signal), one might speculate that any inhibition in such tests is masked as a result of interference at test. It is also possible that the nominally larger RIF effects in the category-cued condition compared to the category-plus-stem-cued condition may be the result of an additive product from interference and inhibition-based RIF effects.

The present findings provide clarity into understanding why RIF occurs, its relation to inhibitory functioning, and how it can be understood in the broader scope of cognition.
Specifically, the current study provides evidence for the notion that RIF is multiply determined based on the dynamics of interference and inhibition. Furthermore, RIF possesses an important process-based quality that is largely determined by how individuals are tested on studied materials. These results send a clear message to researchers who wish to use RIF as a tool to investigate inhibitory control: That care must be taken to select tests that do not confound interference and inhibition in RIF measurements. Finally, the results provide increasing construct validity for RIF as a measure of individual ability to overcome competition in order to correctly recall information, and that from an inhibitory standpoint, RIF is one of many functions of executive control by which we are able to suppress prepotent responses.
V. REFERENCES


Kuhl, B.A., Dudukovic, N.M., Kahn, I., & Wagner, A.D. (2007). Decreased demands on cognitive control reveal the neural processing benefits of forgetting. *Nature Neuroscience, 10*(7), 908-914. doi: [10.1038/nn1918](https://doi.org/10.1038/nn1918)


TABLE I

Average Recall (and Standard Errors) and Significance Tests for Items during the Retrieval-practice Paradigm on Category-cued and Category-plus-stem-cued Tests.

<table>
<thead>
<tr>
<th>Test Condition</th>
<th>Practice Effects</th>
<th>RIF</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Rp+</td>
<td>NRp+</td>
</tr>
<tr>
<td>Category-cued</td>
<td>.67 (.02)</td>
<td>.38 (.02)</td>
</tr>
<tr>
<td>Category-plus-stem-cued</td>
<td>.61 (.02)</td>
<td>.33 (.02)</td>
</tr>
</tbody>
</table>
TABLE II

*Descriptive Statistics for Category-cued and Category-plus-stem-cued Conditions on Stop-signal Reaction Time (in ms)*

<table>
<thead>
<tr>
<th>Test Type</th>
<th>Mean SSRT (SE)</th>
<th>25%</th>
<th>50%</th>
<th>75%</th>
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<tr>
<td>Category-cued</td>
<td>269 (4.67)</td>
<td>238</td>
<td>270</td>
<td>294</td>
</tr>
<tr>
<td>Category-plus-stem-cued</td>
<td>275 (4.72)</td>
<td>245</td>
<td>272</td>
<td>298</td>
</tr>
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</table>
TABLE III

*Hierarchical Multiple Regression Analyses Predicting RIF Scores from SSRTs and RIF Testing Conditions*

<table>
<thead>
<tr>
<th>Predictor</th>
<th>R²</th>
<th>Δ R²</th>
<th>F</th>
<th>β</th>
<th>t</th>
<th>p</th>
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<td>SSRT x Testing Condition</td>
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<td>.001</td>
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* p < .005
### TABLE IV

**Hierarchical Multiple Regression Predicting RIF Scores from SSRTs, RIF Testing Conditions, and Practice Effects**

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<th>Predictor</th>
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* p < .05
Figure 1. *Predicted correlations between individual retrieval-induced forgetting and stop-signal reaction time across test types.*
Figure 2. Correlations between individual retrieval-induced forgetting and average stop-signal reaction time across test types.
Figure 3. Schematic describing example practice and test trials in the Stroop task.

Practice:

XQYZ
UZWY
QWYX
WXQZ

Test (incongruent):

RED
BLUE
GREEN
BLACK
Figure 4. *Schematic describing the procedure of the retrieval-practice task using a category-plus-stem cue.*

**Study Phase**
- SPORT - hockey
- ANIMAL - donkey
- FRUIT - strawberry
- ANIMAL - leopard
- FRUIT - assault
- SPORT - swimming
- FRUIT - mango
- SPORT - volleyball
- ANIMAL - techno

**Retrieval Practice Phase**
- FRUIT - ma
- SPORT - sw
- ...

**Test Phase**
- FRUIT - s
- ANIMAL - l
- SPORT - v
- ...

Figure 5. *Diagram describing the go and stop-signal trials of the stop-signal task.*
### VI. APPENDIX A

*Category-Exemplar Pairs Used in Study Phase of Retrieval-Practice Paradigm*

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<td>Drum</td>
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VII. APPENDIX B

Task Instructions

Initial Instructions:

*You will be completing several tasks in this experiment.*

Retrieval-practice paradigm:

**Study Phase:** *In this next task, you’re going to be shown several word pairs on the screen in front of you. The pairs consist of a category and an item that belongs to that category. For example, you might see RELATIVE – aunt. In this phase, we want you to study and remember the item. Specifically, try to think about how the item belongs to the category. So, for the example, think about how an aunt is a type of relative. You will be seeing several items in each category, and several different categories will be shown. Do you have any questions before we begin?*

**Practice Phase:** *In this phase, you will be trying to remember items that you previously studied. On the screen, you will see a category you previously studied, followed by a two letter cue. The two letters represent the first two letters of a word you studied in the last phase. Please write down this word on the sheet in front of you. For instance, you might see RELATIVE – au. For this item, you write down “aunt.” You will have five seconds to figure out and write down each word. You may see the same cue multiple times, so keep in mind you may repeat your answers. Do you have any questions before we begin?*
Test Phase: Now you will be tested on the items you studied. On the computer screen, you will be shown a cue consisting of a category that you’ve studied before followed by a single letter cue. The single letter represents the first letter that the word begins with. For instance, you might see an item like RELATIVE - a. Please say aloud the word that begins with that letter and also belongs to that category. You will have three seconds to respond to each word before the next item appears. I will be keeping track of your responses on this sheet in front of me. Do you have any questions before we begin?

Stroop task:

Practice: First, we’re going to familiarize you with the initial task. This first part is just practice, so feel free to make mistakes or ask questions. You will be shown a set of letters that are colored either red, blue, green, or black. Please respond with the color of the text as quickly and accurately as possible. To make a response, hit the appropriate key on the keyboard. Each item will be shown for five seconds. Before we begin, please place your middle and index fingers on the appropriate keys on the keyboard. Cues will be available at the top of the screen to remind you which button goes with which color. Do you have any questions before we start?

Critical Trials: Now, you will be doing the same task, except this time the words will be the names of colors. You will be tested many times, and this will take around 10 minutes to complete. Again, please do your best to report the color of the text, not the word itself.
Also, please maintain direct eye contact with the word on the screen. Do you have any questions before we begin?

Stop-signal task:

Practice: In this final task, we’re going to start with a practice session, so again, feel free to make mistakes or ask questions. In this task, you will be asked to do one of two things: Respond to a stimulus or don’t respond to a stimulus. Sometimes, you will be asked to identify one of two types of stimuli that will appear on the screen: Either a circle, or a square. To respond, simply press the circle or square button on the keyboard. Other times, the same stimulus will appear, but you should not respond to it. You will know not to respond because on these trials, because a tone will sound right after the stimulus appears. When you hear this tone, please do your best to not respond. Do you have any questions?

Critical Trials: Now we will begin the actual task. This portion will be longer than the practice phase, and will include short breaks of 10 seconds after you have completed a set. Are you ready to begin?
Approval Notice
Initial Review (Response To Modifications)

January 21, 2011; 2nd Revision 01/28/2011

Rebecca Koppel, BA
Psychology
1007 W Harrison, M/C 285
Chicago, IL 60612
Phone: (703) 220-5117

RE: Protocol # 2010-1018
"Problem Solving and Memory"

Dear Ms. Koppel:

2nd Revision includes the reflection of determination for Research Involving Minors (below), which was inadvertently omitted in the original approval letter.

Your Initial Review (Response To Modifications) was reviewed and approved by Members of IRB #2 by the Expedited review process on January 13, 2011. You may now begin your research.

Please note the following information about your approved research protocol:

Approved Subject Enrollment #: 3400

Additional Determinations for Research Involving Minors: The Board determined that this research satisfies 45CFR46.404, research not involving greater than minimal risk. Therefore, in accordance with 45CFR46.408, the IRB determined that only one parent/legal guardian's permission/signature is needed. Wards of the State may not be enrolled unless the IRB grants specific approval and assures inclusion of additional protections in the research required under §45CFR46.409. If you wish to enroll Wards of the State contact OPRS and refer to the tip sheet.

Performance Sites: UIC
Sponsor: No

Research Protocol(s):

a) Problem Solving and Memory, as submitted to OPRS on 11/17/2010

Recruitment Material(s):

a) Problem Solving and Memory Print Ad, Version 3, 1/4/11
b) Problem Solving and Memory Flyer, Version 3, 1/4/11
c) Problem Solving and Memory Pre-Screening Form, Version 2, 12/1/10
d) Problem Solving and Memory Internet Ad, Version 3, 1/4/11

Phone: 312-996-1711 http://www.uic.edu/depts/over/oprs/ FAX: 312-413-2929
Informed Consent(s):
   a) Waiver of Signed Consent Document granted under 45 CFR 46.117 for Pre-Screening Only
   b) Problem Solving and Memory, Version 3, 1/4/11

Parental Permission(s):
   a) A waiver of parental permission has been granted under 45 CFR 46.116(d) and 45 CFR 46.408(c); however, as per UIC Psychology Subject Pool policy, at least one parent must sign the Blanket Parental Permission document prior to the minor subject’s participation in the UIC Psychology Subject Pool.

Your research meets the criteria for expedited review as defined in 45 CFR 46.110(b)(1) under the following specific category:

(7) Research on individual or group characteristics or behavior (including but not limited to research on perception, cognition, motivation, identity, language, communication, cultural beliefs or practices and social behavior) or research employing survey, interview, oral history, focus group, program evaluation, human factors evaluation, or quality assurance methodologies.

Please note the Review History of this submission:

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Please remember to:
→ Use your research protocol number (2010-1018) on any documents or correspondence with the IRB concerning your research protocol.
→ Review and comply with all requirements on the enclosure, "UIC Investigator Responsibilities, Protection of Human Research Subjects"

Please note that the UIC IRB has the prerogative and authority to ask further questions, seek additional information, require further modifications, or monitor the conduct of your research and the consent process.

Please be aware that if the scope of work in the grant/project changes, the protocol must be amended and approved by the UIC IRB before the initiation of the change.

We wish you the best as you conduct your research. If you have any questions or need further help, please contact OPRS at (312) 996-1711 or me at (312) 355-2939. Please send any correspondence about this protocol to OPRS at 203 AOB, M/C 672.

Sincerely,
Jewell Hamilton, MSW
IRB Coordinator, IRB # 2
Office for the Protection of Research Subjects
Enclosure(s):

1. **UIC Investigator Responsibilities, Protection of Human Research Subjects**
2. **Informed Consent Document(s):**
   a) Problem Solving and Memory, Version 3, 1/4/11
3. **Recruiting Material(s):**
   a) Problem Solving and Memory Print Ad, Version 3, 1/4/11
   b) Problem Solving and Memory Flyer, Version 3, 1/4/11
   c) Problem Solving and Memory Pre-Screening Form, Version 2, 12/1/10
   d) Problem Solving and Memory Internet Ad, Version 3, 1/4/11

cc: Gary E. Raney, Psychology, M/C 285
    Benjamin Storm, Faculty Sponsor, Psychology, M/C 285
Christopher J. Schilling, M.A.
University of Illinois at Chicago
BSB MC 285, 1007 West Harrison Street; Chicago, IL 60607-7137
E-mail: cschil3@uic.edu; Phone: (267) - 322 - 1014

Academic Background

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<td>Moravian College</td>
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<td>Japan Center for Michigan Universities (JCMU)</td>
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Research Experience

Present

Graduate Student, Deep Learning Lab, Univ. of Illinois at Chicago

2010

East Asian and Pacific Summer Institutes (EAPSI) Fellow, Nagoya University

- Proposed and received grant to conduct research with Jun Kawaguchi on context change as it relates to retrieval-induced forgetting.
- Presented work at Japanese national conference sponsored by the Japan Society for the Promotion of Science (JSPS).

2009-2012

Graduate Student, Storm Lab, Univ. of Illinois at Chicago

- Completed research evaluating current usage of measures in retrieval-induced forgetting and their sensitivity to inhibition, and intend to publish.
- Working with an undergraduate on a separate project evaluating competition-dependence in retrieval-induced forgetting as predicted by an inhibitory account.

2008-2009

Research Assistant, Spatial Intelligence and Learning Center, Temple University

- Worked with Nora Newcombe and Thomas Shipley on numerous studies involving spatial cognition
- Designed novel “shattered word” stimuli and methodology for study of student proficiency in the geosciences

2007-2008

Honors Project, Moravian College

- Studied retrieval-induced forgetting (RIF) effects across different domains of item similarity with advisor Sarah Johnson.

Research Interests

- Investigating the concept of desirable difficulties in natural learning settings
- Testing the malleability of working memory through training manipulations.
- Developing a more concrete understanding of cognitive control as it relates to learning and skill acquisition

Other Relevant Experience

Present

Teaching Assistant, University of Illinois at Chicago

- Experience teaching undergraduate-level courses in:
  - Research Methods (4 semesters)
  - Research Statistics for Psychology (1 semester)
Cognitive Psychology (2 semesters)

2005-2008  **Peer Tutor, Moravian College**
- Reviewed course material for undergraduate-level statistics with student groups.
- Created lesson plans in preparation for review.

**Awards**
2012  Psi Chi Regional Research Award (Midwest)
2010  National Science Foundation—East Asia and Pacific Summer Institute Fellow
2008  Distinction of Honors in Psychology
2006  Bridging Scholarship recipient on behalf of The Association of Teachers of Japanese

**Presentations**


Schilling, C.J. (2010). *The real memory test is here?: The roles of experimental context and participant awareness on retrieval-induced forgetting.* Poster presented at the annual meeting of The Japan Society for the Promotion of Science (JSPS), Hayama, Japan.

Schilling, C.J. & Storm, B.C. (2010). *The earlier they come, the harder they fall: Testing the competition dependence assumption of retrieval-induced forgetting.* Poster presented at the annual meeting of The Psychonomic Society (Psychonomics), St. Louis, MO.


**Skills and Abilities**
- Proficient in programming languages and script writing common in the cognitive sciences (E-Prime, C++, Psyscope, SPSS, Microsoft Excel)
- Proficient Japanese language ability in reading, writing, and speaking.
- Skilled in use of various video editing software (e.g. Sony Vegas Pro)
- Expertise in writing style, editing principles, and interface related to Wikipedia.