The Role of Inhibitory Control in Working Memory Capacity and Reasoning Ability

by

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ABSTRACT

Retrieving an item from memory can cause subsequent suppression of related items. This phenomenon, involving a procedure where participants retrieve category-exemplar pairs (e.g. FRUIT-orange), is known as Retrieval Induced Forgetting (RIF). Individuals who demonstrate greater amounts of RIF also exhibit greater working memory capacity (WMC). Reasoning ability is highly related to WMC, which may suggest that a similar relation exists between RIF and Reasoning ability. The goal of the present investigation was to examine this possibility. Rotation Span and a Letter Number task were used as indicators of WMC and a Cognitive Reflection Test was used to measure Reasoning ability. A significant RIF effect was found, but it did not significantly correlate with WMC or Reasoning ability. These results demonstrate the importance of designing a RIF task appropriately, selecting measures of Reasoning ability, and the theoretical accounts of the RIF effect. One possibility is that by not controlling for output interference, the obtained RIF effect cannot be reasoned to come from the executive control process as suggested by the inhibition account. Although this account is the chief explanation of the RIF effect, it has been challenged by alternative accounts and it remains unclear how the underlying mechanism of RIF is related to higher cognitive abilities.

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Introduction

Inhibition in Memory

It is rather counterintuitive to think that forgetting can aid memory, but without it our mental functions would suffer immensely. Forgetting facts or pieces of information allows individuals to adapt to new environments. Sometimes, memory is better off when previous items – like the code to an old combination lock when trying to remember a new one – are forgotten. Executing a task requires the release of information from the past, especially if those previous items closely resemble the current task. Inhibiting outdated information may enhance the capacity for retaining new and relevant information.

Take for example, if someone were trying to recall a newly released episode from their favorite television show. Perhaps in the course of searching memory for the current episode, interfere arises from the similarity that a previous episode has on the current one. Searching memory for the content of the that recent episode not only requires focus on that one task, but also the swift essence of inhibition for interfering information, such as the related events from episodes in weeks past.

Inhibition and suppression are nuanced ideas in cognitive psychology. Although researchers have long been interested in what role inhibition process has in the study of higher cognitive abilities (Dempster, 1991), its role as an explanation for many phenomena falls behind concepts like processing speed, executive function, and attention control (Sternberg & Detterman, 1986). The simplest and most salient characteristics of high cognitive ability are attention control, a large capacity for new information and the ability to problem solve in new environments (Neisser et al., 1996).

Perhaps explanations and theories that argue in favor of inhibition go unnoticed due to its inconspicuous nature. Consequences can arise from an abundance of motivation to see what is immediately obvious to us, as demonstrated by situations of confirmation bias (Wason, 1960). Therefore, one way in which to extend the study of higher cognitive abilities it to examine alternative explanations.

Retrieval Induced Forgetting

Investigating the role of inhibition has recently become possible with a new and growing body of literature on Retrieval Induced Forgetting (RIF). This paradigm largely supports the role of inhibition in memory retrieval. The RIF effect is a demonstration of how retrieving items from memory can cause subsequent inhibition for related items. In other words, forgetting is a consequence of retrieval.

Research on RIF has gained popularity in recent years as indicated by a recent meta-analysis by Murayama and colleagues (2014). Since 1994, researchers have written almost 200 articles related to RIF. This phenomenon is typically found with a procedure where participants see and recall certain category-exemplar pairs (e.g. FRUIT-orange). The RIF effect has also been show in other contexts, such as propositional knowledge, (Anderson & Bell, 2001), visuospatial materials (Ciranni & Shimamura, 1999), eyewitness testimony (Shaw, Bjork & Handal, 1995), autobiographical memory (Barnier, Hung & Conway, 2004) and foreign-language acquisition scenarios (Levy, McVeigh, Marful & Anderson, 2007).

Within the procedure, people first see a series of different category-exemplar pairs. Then, category-exemplar-letter stems from half of the exemplars from half of the categories from that list are shown (e.g. FRUIT-or____); to which people are asked to

finish the partial word. Giving the person a recall cue to a certain word allows the researcher to guide which item people retrieve. At final test, the category names (e.g. FRUIT) appear and people must generate as many exemplars as possible (there are normally 6 possible exemplars for each category). The effect is typically measured by calculating the difference in recall accuracy for related non-practiced items and non-practiced categories.

Retrieving an exemplar (e.g. FRUIT, orange, termed RP+ [practiced exemplars belonging to practiced categories] in the literature) that belongs to the same category as an item that did not undergo a retrieval attempt (e.g. lemon, strawberry, termed RP- [nonpractice exemplars belonging to practiced categories] in the literature) unsurprisingly results in higher accuracy for that item (RP+) at test compared to an item that was not practiced (RP-). The critical feature of RIF is the *forgetting* (i.e. lower accuracy) of an unpracticed item (RP-), relative to an item that was seen only at study (e.g. Metals – Iron, Steel, termed NRP [nonpractice exemplars belonging to nonpractice categories] in the literature). The Reasoning is that because RP- and NRP items are shown the same number of times – just once during study phase – recall accuracy should be equal for both. The only notable difference between NRP and RP- items is that RP- items share the exact same category as an RP+ item.

Although inhibition is the chief explanation of RIF in this study, alternative explanations that include context and interference are considered in the discussion.

Figure 1 Retrieval Induced Forgetting Items

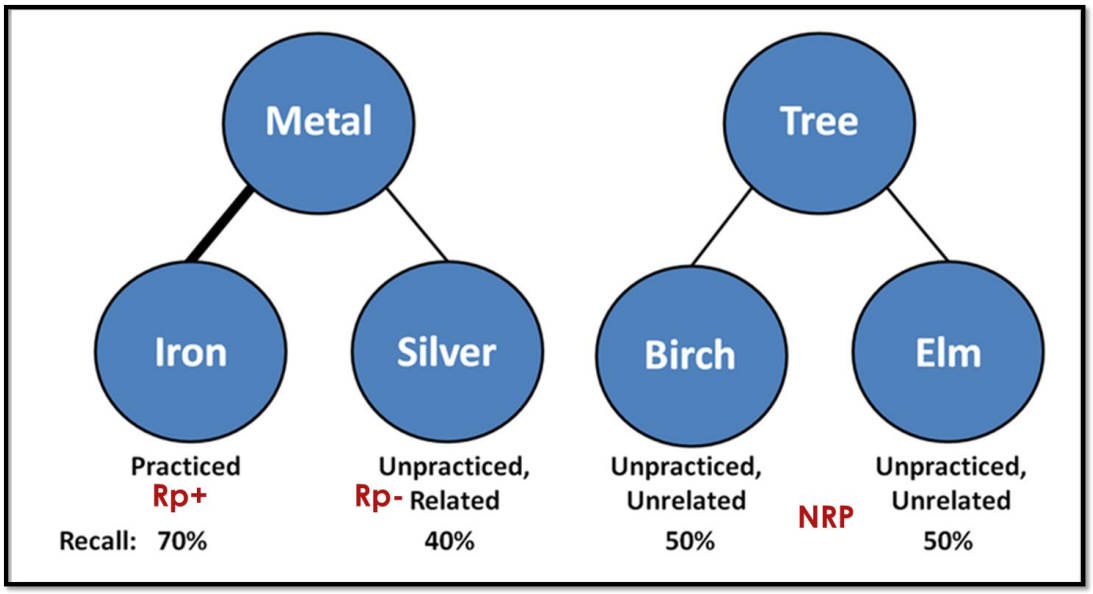


Figure 1 represents four example items from the RIF procedure. RP+ = Target Retrieval Practice Items; RP- = Non-Target Retrieval Practice Items; NRP = Non-practiced Retrieval Items. Hypothetical percentages of recall accuracy are included for each of the three items in the very bottom of figure in line with the text that reads "Recall:".

The Inhibition Account of Retrieval Induced Forgetting

Many researchers have argued that inhibition is the chief mechanism underlying RIF (Anderson, 2003; Anderson & Levy, 2002; see also Bäuml, 2007; Bjork, Bjork, & Caughey, 2007; M. D. MacLeod & Hulbert, 2011; M. D. MacLeod & Saunders, 2008; Norman, Newman, & Detre, 2007; Storm, 2011; Storm & Levy, 2012). The retrieval of a target item (e.g. orange), causes the spreading activation for surrounding items to that target (e.g. banana, strawberry), in addition to the target itself (Blaxton & Neely, 1983; Anderson et al. 1994). According to some theories on spreading activation, lateral inhibition protects a target word from non-target words, thus making it possible for

successful retrieval of that target word (Dagenbach, Carr and Barnhardt, 1990). While a target exemplar is activated in a memory search, non-target exemplars undergo some degree of activation in addition to the target exemplar. The inhibition account suggests that an executive-control process is recruited to resolve the activation of non-target exemplars, and therefore resolves the possible interference between the two (Anderson & Levy, 2002).

In a study by Anderson and Spellman (1995), additional support for an inhibition account was provided by experimenting with how the suppression for one item affects another unexpected item. In their pattern suppression model, cross-category inhibition was examined, in which RP- and NRP items share similar features. Their finding that the inhibition of an RP- item can inhibit an NRP item suggests that the activation of an items characteristics spreads laterally. Thus, inhibition, or the forgetting effect, can affect items other than a RP- item. The experiment never presents the RP- and NRP items together, rendering their relationship non-explicit. Inhibition of RP- items bleeds through categories, thereby suggesting the item level experiences inhibition, as opposed to a higher level of abstraction, such as an entire list or category. Item-level inhibition is thought to be driven by the feature based representation of category-exemplar pairs.

The executive control process recruit's inhibition to resolve the competition between target (RP+) and non-target (RP-) words by inhibiting the non-target word. During the practice phase, people must create a search set in memory so that they can arrive at the correct response to category-exemplar-letter stems. When a person generates a search set by whatever means necessary (for example: creating a network of possible matches to the category-exemplar-letter stem) they activate both the target and

non-target words. Target and non-target words compete simultaneously to be categorized as the "correct" response. As a byproduct of choosing the correct response (target word [RP+]), the incorrect response (non-target [RP-]) is inhibited. In other words, inhibitory control resolves the competing activations by inhibiting the non-target word.

Although RIF represents an experimental technique for inducing the inhibition / suppression for certain items, it can be understood in analogous situations. For example, suppose that you have had 12 different soccer coaches in your lifetime. Each time that you recall the name of one soccer coach (e.g. Bob), the names of the other soccer coach's that have mentored you are inhibited, rendering them less able to be recalled later on. The poorer recall for that related name, as depicted by the inhibition account, is the consequence of the goal-directed process that facilitates retrieval. In other words, the forgetting can be thought of as one naturally occurring process in memory retrieval.

The major underlying mechanism that is believed to be responsible for the RIF effect is an executive control process. The interference arising at practice phase where a category name (e.g. FRUIT) activates exemplars (e.g. apple) must be dealt with in order for a response to be made. The action that's hypothesized to take place is that leftover interference between the target and non-target items is resolved with an executive control process. The RIF effect represents an action to inhibit the non-target word items so that the target items can be successfully retrieved. Poor recall accuracy may reflect instances in which this interference is not resolved.

The executive control process present in the RIF task shares similarities with the underlying mechanisms involved in other measures of attention and memory. For

example, Working Memory Capacity is believed to represent both attentional control and memory processes. The combination of these two is a very potent indicator of cognitive ability and as a whole relates to concepts like Reasoning ability, even when controlling for verbal ability and short term memory (Engle, 2002). Comparing RIF performance to something with a similar underlying explanation may perhaps aid the breakdown of what exactly their executive control processes represent.

Cognitive Abilities

The field of cognitive abilities research relates to the disputed accounts of the Retrieval Induced Forgetting effect. For example, tests that measure aptitude and IQ stem from the longstanding history of interest for comparing individuals within the workforce, military and academics. Central components and factors derived from these assessments are Reasoning ability and Working Memory Capacity.

Reasoning represents problem solving ability and Working Memory Capacity is the ability to maintain relevant information. Reasoning ability is important to understand because of its predictability for professional and academic success (Neisser et al., 1996). Working Memory Capacity has predictive value to a wide range of cognitive abilities (Engle, 2002), such as reading comprehension (Daneman & Carpenter, 1980; Turner & Engle, 1989) and performance on college entrance exams (e.g., SAT, ACT'; Cowan et al., 2005; Turner & Engle, 1989). Although both of these represent unique aptitudes, studies show that they are highly related constructs, sharing as much as 80% of their variance (Kane et al., 2005; Oberauer et al., 2005; Shipstead et al., 2014).

One interpretation is that these two constructs are one in the same; the only difference is the names that they carry. Constructs in cognitive psychology such as primary memory, secondary memory, focal attention, and attention control, are correlated with Working Memory Capacity and are used to understand individual components that make up these broader constructs (Kane et al., 2004; Shipstead et al., 2014). However, the study of Reasoning ability has not been as popular of a topic, compared to Working Memory Capacity. A core purpose of this study was to add to the study of Reasoning ability by picking apart its components by comparing it to studies on RIF.

Investigating the points at which these constructs differ will help solidify the semblance of higher cognitive abilities. Recent studies have taken on this endeavor by separating these two processes by means of multivariate analysis, such as structural equation modeling and confirmatory factor analysis. Shipstead et al. (2014) utilized these methods and have been able to show that attention control and memory have differing relations to Working Memory Capacity and Reasoning ability.

Current Study

Goals

The goal of this study is to investigate the role of inhibitory control in Working Memory Capacity and Reasoning ability. Seeing that these concepts all utilize an executive control process in some amount, inferences about what is similar among these tasks may be able to be recognized. Creating a more complete understanding of how these constructs differ can add to the current theoretical explanations of them.

Rationale

Both Working Memory Capacity and Reasoning ability are unique aptitudes, even though studies show that they are highly related constructs, sharing as much as 80% of their variance (Ackerman, Beier, & Boyle, 2005, Kane et al., 2005; Oberauer et al., 2005; Shipstead et al., 2014). Performing a cognitively demanding task requires the maintenance and focus of attention and the correct suppression and constant inhibition of irrelevant information. The efficacy with which one can conduct this process in addition to maintaining relevant information determines their Working Memory Capacity (Mogle, Lovett, Stawski, & Sliwinski 2008).

A recent development in the cognitive abilities literature is the finding that a unique relation exists between attention control and Working Memory Capacity, apart from Reasoning ability. For example, Shipstead et al. (2014) found that attention control (i.e. attention) does not affect Reasoning ability above its contribution to Working Memory Capacity. Attentional control has a central role in accounting for the many aspects of Working Memory Capacity, suggesting that its relation is exclusive to it. In

other words, “Any effect that attentional control has on novel Reasoning is realized through an effect on memory” (Shipstead et al., 2014, pg. 137).

The process of inhibiting outdated or irrelevant information is necessary to complete a Working Memory task. Expelling previously activated information that is no longer relevant to the current task allows mental resources to be reallocated to an immediate goal (Brewin et al., 2002). Examining how inhibition relates to Working Memory Capacity is a logical follow up to this idea. Combating distractions is a key component within almost any Working Memory Capacity test. Working Memory Capacity can predict performance on inhibitory control tasks such as the Stroop task, or the antisaccade. People with high Working Memory Capacity have shown better performance on these tasks (Kane & Engle, 2003; Kane, Bleckley, Conway & Engle, 2001). In addition, Mogle et al. (2008) and Unsworth & Spillers (2010) asserted that the function of retrieval is central to performing Working Memory Capacity tasks.

A study by Storm & Angello (2010), discovered that individuals who overcome fixation in a Remote Associates Task also show greater levels of Retrieval Induced Forgetting. The fixation – the interference between a solution that is incorrect and other plausible answers that have not yet been retrieved from memory – is resolved with an inhibitory control process. One explanation of the relationship is that those with greater inhibitory control demonstrate this ability in more than one task. Overcoming fixation by usage of inhibitory control is a plausible explanation for why those who show greater RIF also demonstrate greater problem solving ability.

A gap in the literature that this study addresses is the extension that Retrieval Induced Forgetting has to the field of cognitive abilities, namely how the kind of

inhibitory control that is used in a measure of cognitive ability may relate to the kind of inhibitory control that is used in the RIF Task. Three other studies that looked at the relation between RIF and Working Memory Capacity found mixed correlation's. Aslan & Bauml (2011) and Storm & Bui (2015) observed a positive correlation between RIF and Working Memory Capacity while Mall (2014) found a negative correlation between the two variables.

Two major design differences between these studies are the type of test phase (recognition vs. recall), the length of the distractor segment (2 minutes versus 20). These mixed results are likely due to the mentioned design differences between the three studies. In order to alleviate concerns for inconsistent results, the same design and materials as those found in the first article to measure RIF were used in the current study (Anderson, Bjork, & Bjork, 1994). Their materials include high semantically related word-pairs, a distractor phase of at least 10 minutes and a recall final test. The article by Anderson and Colleagues (1994), was the first publication on the RIF effect and its design and materials have been used in a number of replication studies since then (Murayama et al., 2014).

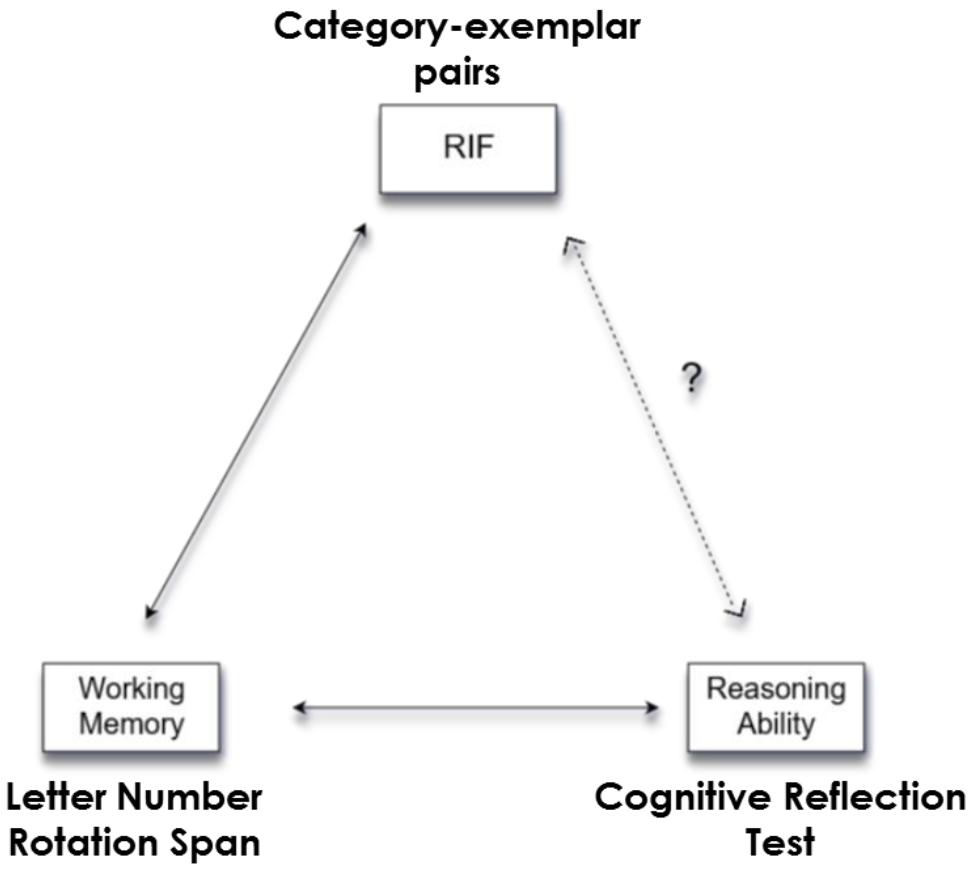
This study proposes a new approach: Inhibitory control is an independent aspect of executive function. One aspect of executive control is the ability to flexibly adapt and stop unwanted processes from occurring. Support for this description comes from a study by Levy (2008), which found that individual differences in executive control mediated the ability to combat intrusive memories. If Working Memory Capacity and Reasoning ability have such a strong correlation, and if Working Memory Capacity is predictive of inhibitory control tasks, then Reasoning ability should be predictive of inhibitory control

tasks as well. It is expected that inhibitory control is uniquely predicted by Reasoning ability, controlling for the influence of Working Memory Capacity.

Hypothesis

The hypothesis of the current study is that Reasoning ability will be positively correlated with RIF, controlling for Working Memory Capacity. Figure 2 represents the predicted model of the current study. The two double headed arrows with solid lines represent the previously established relationships. The goal of the current study is to establish the relation as depicted by the dashed double headed arrow with a question mark.

Figure 2 Predicted Model



RIF = Retrieval Induced Forgetting; Working Memory = Working Memory Capacity. Working Memory Capacity was measured with two indicators – a Letter

Number task and a Rotation Span task. Reasoning ability was measured with the Cognitive Reflection Test and Retrieval Induced Forgetting was measured using category-exemplar pairs. See Appendix A for a complete list of the stimuli used in the RIF task.

Method

Subjects

Data were collected from students at Arizona State University – West Campus. Written informed consent was obtained from every participant prior to the study, and the procedure was approved by the Arizona State Universities Institutional Review Board. Participants received partial credit for a course and were run individually with an experimenter present. Four of the 129 subjects that participated were dropped because they did not meet the age requirement. Participants were between 18 and 35 years of age. (M_{age} = 22.4, SD = 3.8). All tasks were administered on a computer.

Procedure

Participants took between 40-60 minutes to complete four measures. The first administered task was the Retrieval Induced Forgetting task, followed by the Rotation Span, Cognitive Reflection Test and finally the Letter Number task.

Task Selection

Retrieval Induced Forgetting.

The RIF task that was given to participants used the same category-exemplar pairs that were used by Rowland et al. (2014) to measure RIF. Eighteen different categories were selected with 6 exemplars for each. In total, there are 108 category-exemplar pairs – 12 of which serve as fillers. All category-exemplar pairs are taken from the Norms of Word Associations (Marshall, and Cofer 1970). Pairs meet the same criteria set by Anderson (1994) − no two exemplars began with the same first two letters within a category and categories are relatively unrelated (e.g. FRUITS vs. METALS).

Forty-eight of the pairs were taken directly from the strong word condition of Anderson (1994) and the remaining 60 from Rowland et al. (2014).

There are four sequential phases to Retrieval Induced Forgetting task: study, practice, distractor and test. **1.** In the study phase, all of the pairs are shown individually for 5 seconds. Participants are instructed to think about the relation between the category and the exemplar. In total there are 4 sets of conditions that participants engage in for counterbalancing purposes. **2.** In the practice phase people are told they will see an incomplete category-exemplar pair (e.g. FRUIT-ba) and will need to complete the partially spelled word by typing out the remaining letters to the partial word. For counterbalancing purposes, people are randomly assigned to one of 4 partials out the counterbalancing? versions of this phase. The pairs are made up of half of the exemplars from half the categories. In other words, 3 exemplars from 8 categories are chosen as practice pairs (in total, 24 pairs). Four versions of this phase were created to counterbalance which pairs are shown since during practice, only one quarter of the total possible pairs are presented. Each version is identical in procedure and only differ based on the subset of pairs that are presented. All items were presented three times each on an expanding schedule. The spacing between the first and second instance of a pair had to be less than half the size of the space between the presentation of the second and third instance of that same pair. **3.** In the distractor phase, participants completed a rotation span task. **4.** In the test phase, participants are shown one category name for 30 seconds and instructed to type out as many exemplars of that category as possible. They are also told that they should only produce exemplars that correspond to a pair that was present during the entirety of the experiment. There are three kinds of items after the final test –

RP+, RP- and NRP. After the Retrieval Induced Forgetting task was completed, participants took the cognitive reflection test and then the letter-number task. The order of all of these tasks was fixed to avoid subject by treatment interactions.

Rotation span.

The procedure of this task very similar to the Rotation Span used by Kane, Hambrick, Tuholski, Wilhelm, Payne, & Engle (2004). Participants recalled short and long arrows radiating from the center of the screen interleaved with a letter-rotation task. The letter rotation task presented a normal or mirror-reversed G, F, or R (approximately 2 cm tall), rotated at 0°,45°,90°, 135°,180°, 225°, 270°, or 315°. Participants are told to mentally rotate the letter and indicate with a key press whether the letter was normal ("yes") or mirror reversed ("no"). The letters were shown in the normal juxtaposition about half the time. Immediately after this response, a blank screen appears for 500 ms with a short or long arrow (identical to those used in the arrow span STM task) for 1000 ms. Following the offset of an arrow, a letter or recall cue appears. When presented with the recall cue, participants are asked to recall all of the arrows from the preceding displays, in the order they appeared. Set sizes ranged from two to five letter–arrow displays per trial (for 12 trials total). Participants final scores reflect the total number of correctly recalled arrows. Only on the trials where participants correctly recalled the rotated letters were the arrows counted toward their final score.

Cognitive Reflection Test.

The Cognitive Reflection Test (CRT) consists of three different word problems. An example question from the task: If a bat and a ball cost $1.10, and the bat costs $1.00

more than the ball, how much does the ball cost? The first response for most participants is the incorrect answer (10 cents). Frederick (2005) argued that the CRT measures cognitive reflection – the ability to deter an initial response and reflect more deeply about the question. Only after careful cognitive reflection is a person able to generate the correct answer to the question (5 cents). Lubinski and Humphreys (1997) suggested that decision making preferences are determined by cognitive abilities or some aspect of intelligence. Frederick found this test to be a strong predictor of decision making preferences within a variety of gain/loss scenarios that used monetary incentives. He posed CRT as a cognitive abilities test and that is moderately correlated to other cognitive abilities tests, such as the ACT, Wonderlic Personnel Test and SAT (correlations of .46, .43 and .44, respectively). The CRT is a powerful test because it is very short in length (ACT, SAT, Wonderlic take over 3 hours versus the 1-2 minute CRT), and predicts decision making preferences with higher accuracy than the longer tests (Frederick, 2005).

If the CRT is a powerful predictor of decision making preferences, and decision making preferences can be indicative of at least one aspect of general intelligence (Lubinski & Humphreys, 1997), then the CRT could be a criterion of intelligence. This is precisely what we intend to use the CRT for in our study. A participant must override their initial answer to the question in order find the correct solution to the problem. Reasoning ability is a factor that is commonly found in general abilities tests and represents one's ability to reason with novel information.

Letter number task.

The letter number task originates from complex working memory tasks that were first used for neurophysiological research (Gold, Carpenter, Randolph, Goldberg, &

Weinberger, 1997). A standardized version of the letter number task is included in the Wechsler Adult Intelligence Scales (WAIS; Psychological Corporation, 1997) and the Wechsler Memory Scale (WMS; Psychological Corporation, 1997). This test requires people to maintain and manipulate items in working memory. A series of letters (e.g. R, L) and numbers (e.g. 5, 3) are shown individually. Once the presentation sequence ends, the participant is asked to recall all of the letters and number separately in ascending order (e.g. L, R – 3, 5). The task begins with 2 letters and 2 numbers. Trials containing the same number of items are repeated three times with different letter and number combinations. If the participant successfully completes the three trials, a new set of three trials with one additional item is presented (e.g. L, R, Q – 3, 5). The procedure is repeated until the participant cannot recall 2 out of the 3 from a given set. The maximum number of items that a participant can recall without any errors is their score.

Several functions are involved in the letter number task, such as item manipulation and set switching between letters or numbers. These same functions are also involved in Working Memory Capacity tasks, such as a complex span task. Therefore, we used the letter number task as one of our two indicators of Working Memory Capacity.

Results

A paired samples t-test revealed a significant Retrieval Induced Forgetting effect. Retrieval Induced Forgetting score is calculated by subtracting an individual's RP- score from the NRP item score. For example, to calculate an individual's recall accuracy for NRP items, the total number of correctly recalled NRP items (e.g. 23) is divided by the total possible number of NRP items (e.g. 48), resulting in a NRP score of (23/48) ≈ .48. To conduct this test, individual scores of accuracy for NRP and RP- items are compared with one another. A significant Retrieval Induced Forgetting effect was found t (125) = 2.59, $p < 0.001$ with NRP items recalled with higher accuracy (M = 0.37, SE = 0.02) than RP− items (M = 0.29, SE = 0.02, [*see Table 1*]).

Table 1. Descriptive Statistics

Variable	Min	Max	M	SD	Sk	Kurtosis
CRT	0.00	3.00	0.45	0.86	1.89	2.51
LetNum	0.00	19.00	10.00	3.83	-0.99	1.51
NRP	0.00	0.94	0.37	0.19	-0.33	0.08
RIFscore	-0.19	0.33	0.07	0.10	0.22	-0.19
RotSpan	0.00	39.00	24.98	8.05	-0.77	0.83
RP-	0.00	0.79	0.30	0.19	0.09	-0.63
RP+	0.00	0.96	0.56	0.29	-0.70	-0.55
Total Recall	0.00	2.61	1.23	0.61	-0.67	0.73

Note. CRT = Number of correctly answered questions on Cognitive Reflection Test; LetNum = Score on Letter Number task; NRP = Recall accuracy for Non-Retrieval Practiced items; RIFscore = calculated amount of Forgetting (RP- subtracted from NRP); RotSpan = Score on Rotation Span task; RP- = Recall accuracy for Non-Practiced items belonging to Practiced Categories; RP+ = Recall accuracy for Practiced items belonging to Practiced Categories; Total Recall = NRP + RP- + RP+.

Both of the Working Memory Capacity measures were significantly correlated to one another ($r = .44$, $p < .01$) and one measure of Working Memory Capacity was significantly correlated to Reasoning ability (Letter Number Task and Cognitive Reflection Test [$r = .22$, $p < .05$]).

Table 2. Correlation Matrix

Task	1. RIFscore	2. CRT	3. LetNumb	4. RotSpan
1. RIFscore	1.00			
2. CRT	-.07	1.00		
3. LetNum	.09	.22*	1.0	
4. RotSpan	-.09	.16	.40**	1.0

$p < 0.05$ = *, $p < 0.01$ = **

In an attempt to refine our observed variables, a composite score of the two Working Memory Capacity measures was created. Using this composite score in a bivariate analysis did not result in a significant correlation between Working Memory Capacity and RIF, or even Reasoning ability. A possible confounding variable that arises from counterbalancing procedures is that the results may reflect the condition that a participant was placed in. Overall, there was not a significant difference in RIF scores between the four versions F (124) = 0.98, $p < ns$.

Discussion

Overview

The goal of the current study is to tease apart Working Memory Capacity and Reasoning ability by examining the relation they have to Retrieval Induced Forgetting, an indicator of inhibitory control. One aim of this study was to address the incomplete results of the relation between Retrieval Induced Forgetting and Working Memory Capacity. The second is to tease apart the strong relation between Working Memory Capacity and Reasoning ability by examining their relation to Retrieval Induced Forgetting.

A multiple regression analysis allows for the effects of Working Memory Capacity to be controlled for, revealing the unique relation that inhibitory Reasoning ability has with Retrieval Induced Forgetting. However, the results of our bivariate analysis render a multiple regression analysis futile because there were no significant correlations between the variables of interest. The only significant correlations that exist are between the two measures of Working Memory Capacity, and between the Cognitive Reflection Test and the Letter Number task (see Table 2).

Reasons for an Absence of Expected Results

One possible reason why the expected results were not obtained is that our indicator of inhibitory control, the Cognitive Reflection Test, had a very skewed outcome. Ninety-four out of the 125 participants (approximately 75%) did not get any of the three questions right. In other words, people typically did very poorly on this task. Although motivation for using this test as an indicator of Reasoning

ability comes from its medium correlation to Fluid Intelligence (r = .34, Brañas-Garza, et al., 2012).

Variability within the Cognitive Reflection Test is limited because of its small range of possible scores (0 to 3), while comparatively the measures of Working Memory Capacity have much greater potential for larger variability. It is difficult to find strong or even significant correlations with a relatively small possible magnitude of variability.

The small RIF effect that was obtained may also be another reason that we did not obtain the expected results. The actual amount of *forgetting* in the Retrieval Induced Forgetting task is represented by a 7% difference in recall accuracy between NRP and RP- items. As indicated by previous research, the RIF effect is typically small and can vary depending on the group of participants recruited for the study Rowland et al. (2014).

In addition, a mean weighted RIF effect size of .50 was shown in a group of 256 samples that was similar to the procedure used in this experiment; with 95% confidence intervals [.45, .55] Murayama et al. (2014). Seeing that the effect size found here is far below the lower confidence interval of the mean statistic from this meta-analysis, our small effect size is difficult to interpret.

The magnitude of the two positive correlations between RIF and Working Memory Capacity found in previous studies were medium or weak (Pearson's r between .35 and .41). In addition, the study by Mall et al (2014) found a non-significant negative correlation between the two. Combined, these findings reflect the difficulty with replicating such a correlation. Previous evidence of a

weak correlation or even a lack of significant correlation makes it difficult for future studies to obtain similar results.

Disputes over Accounts of Retrieval Induced Forgetting

The original account of Retrieval Induced Forgetting proposed an inhibitory control mechanism as the chief explanation of the effect (Muryama et al., 2014). Since that time, the usage of one critical experimental manipulation has governed whether or not the inhibitory control can be used as the explanation for this effect. The inhibition account of forgetting effect can only be the favorable explanation if output interference is controlled for.

Output Interference is a confounding variable in memory experiments where a subject relies on the order of the presented stimuli, as opposed to an alternative strategy. If such a strategy is used, then it could be argued that what you're actually measuring is not memory performance, but rather how well a participant was able to chunk or order together the stimuli shown to them.

Controlling for the effects of output interference is accomplished by designing phase 4 of the RIF procedure to mimic that of phase 2, thereby guiding the retrieval of each individual exemplar. This process encourages the participant to retrieve an exemplar from memory by the same process that was used during the practice phase and does not allow the order in which the items were presented to aid retrieval.

Output interference was not controlled for in this experiment. Therefore, one potential reason for our lack of expected results is that a potential confound was not adequately controlled for. While the RIF effect we found was significant,

it is potentially the result of mechanism other than the executive control process argued by the inhibition account (Storm et al., 2015). As suggested by a meta-analysis on Retrieval Induced Forgetting, "If RP- items suffer more output interference at test than NRP items, then RIF may be observed at final test even if RP- items were not actually inhibited during retrieval practice." (Muryama et al. 2014, pg. 1387).

Moreover, within the two studies that found significant correlations between RIF and Working Memory Capacity, output interference was controlled for. While speculative, it is likely that a condition of these correlations is that output interference is controlled for. Future research could investigate why this relation is only found in studies that control for output interference.

Even though the focus of the current study is on the inhibition account of RIF, two alternative accounts (Interference & Context) contest the inhibition account and should therefore be addressed. The Interference account asserts that the RIF effect is interference dependent – that is to say that without the high semantic relation between the category and exemplar, the RIF effect is very small or even non-existent (Murayama et al. 2014). The context account manipulates the mental context that adjoins the different phases of the RIF task so as to show how the effect can disappear when a simple condition is not met Jonker, Seli, & MacLeod, (2013).

Context account.

Jonker et al., (2013) argues that context plays a central role in the RIF effect. Their account states that RIF will only occur if two conditions are met. The first condition is that a context change must occur between the study and practice phases. The

second is that the practice context must be active during the test phase. In a series of three experiments, results indicated that the RIF effect was not found when neither or only one of the conditions were met. Although context has been considered by some (Anderson and Bjork, 1994; Perfect et al. 2004; Camp, Pecher, and Schmidt, 2007), its role has never been explicitly tested nor has it been applied to the literature on the RIF effect.

Memory is contextually driven, and reactivating context at retrieval facilitates remembering (Eich, 1980; Smith & Vela, 2001). The retrieval process itself causes a shift in mental context (Jang & Huber, 2008; Sahakyan & Hendricks, 2012). Jonker et al. (2013) critically examined the inhibition account and found that context can explain instances of RIF without considering the necessary conditions set by the inhibition account. The context account is an independent explanation of RIF and therefore poses some challenges for the other two accounts.

Interference Account

An alternative explanation to this analogy is that the soccer coach's names simply interfere with one another. The thinking is that an uncommon name, such a Cayson, has a preexisting, lessened chance of being recalled due to its obscure relation to "soccer coach". The original article on RIF (Anderson, Bjork & Bjork, 1994) found exactly that; less common exemplars show a significantly smaller forgetting effect than do highly related exemplars. It is plausible that the inhibition mechanism best explains situations when the category and the exemplar possess a strong associative connection and interference is the best explanatory mechanism for cases when there is not. The

inhibition account is challenged by the interference account because it cannot explain all cases of RIF.

Anderson & Bjork (1994, Experiment 3) considered the implications of their findings of a significantly lower RIF effect for exemplars that have low versus high taxonomic frequency. The significantly smaller RIF effect suggests that when target and non-target items have a weak relation to the category name, their susceptibility to RIF is lessened. Exemplars with low taxonomic frequency have a decreased chance of being activated during the practice phase. Thus, the effect has been suggested to be interference dependent (Murayama et al. 2014).

Although interference best explains RIF in situations involving weakly related category exemplar pairs, the inhibition account can explain a majority of the forgetting effects found in a wide variety of domains where interference cannot (Murayama et al. 2014).

The support for alternative accounts of RIF is generated by the boundary conditions of the effect itself and the inconsistent relation it has to other constructs, like Working Memory Capacity. For example, the context-change account asserts that the RIF effect only occurs if both conditions are met: Mental context must differ between the study phase and practice phase, and the practice context must be active during the test phase.

An experiment by Storm & Bui (2015) showed that when the impossible practice – a type of practice phase of RIF where the category exemplar stem's do not match items shown in the study phase – is used, the correlation between RIF and Working Memory Capacity goes away. This finding suggests that the relation

originates, at least partially, from the practice phase. A logical deduction from these findings is that at least some degree of interference must exist between the target and non-target words, otherwise the correlation disappears.

The interference account asserts that practiced items "get in the way" of the non-practiced ones, resulting in poorer recall relative to baseline items. Testimony to the importance of interference are studies on strongly versus weakly related category exemplar pairs. In the original Anderson et al (1994) paper on RIF, it was found that the magnitude of the RIF effect was smaller when the category-exemplar pairs were weakly related to each other (lower taxonomic frequency). However, this has been shown to not be a general effect (Williams, & Zacks, 2001). What's clear is that each of these theories contribute individually to the overall explanation of the RIF effect. No single account can explain all findings and the best explanation has to account for the conditions set forth by each.

Retrieval Induced Forgetting Joined with Cognitive Ability

Working memory capacity.

The application of RIF to the field of cognitive abilities is underexplored. One intention of this study was to build upon the three previous articles that compared RIF to Working Memory Capacity. The overlapping variability between the two constructs is not straightforward, as their relation only appears in procedures that control for output interference. While Working Memory Capacity positively correlates with tasks that require inhibitory control, such as the antisaccade or Stroop (Kane & Engle, 2003; Kane, Bleckley, Conway & Engle, 2001). The specific components of executive function

necessary to complete these tasks have been thought to represent the same components involved in RIF. Seeing that two studies (the present and Mall et al. [2014]), have such a relation, it may be deduced that they do not share the same variety of executive control components.

If we did in fact find a relation between the two, the next step would have been to tease apart the strong relation that Working Memory Capacity has with Reasoning ability. This next step would provide two things: 1.) To create a more complete depiction of either construct, as they may or may not relate to inhibitory control and 2.) to also indicate what magnitude of an individual's RIF effect means to the underlying mechanism to the RIF effect. Our results indicate that our measures for Reasoning ability and Working Memory Capacity are not problematic, as expected they did correlation with one another. Therefore, it's worth making note that we expected and did in-fact observe some common variance between these measures.

Conclusion

The present study examined how inhibitory control relates to Working Memory Capacity and Reasoning ability. The naturally occurring process of forgetting of items related to the retrieval of a target item was positioned in this study as a component that makes up the broader concept of cognitive ability. While it has been shown in the past that those individuals who show greater retrieval induced forgetting effects also have greater Working Memory Capacity, this study's purpose was to extend that finding as it relates to Reasoning ability. I hypothesized that suppressing inappropriate or outdated information may also be demonstrated in tasks that measure inhibitory control.

Undoubtedly, one component of executive function is the suppression or inhibition for irrelevant information. The present study represents an attempt to tap into that component. This study represents the second finding of no relation between RIF and WMC when output interference is not controlled. It also makes for the case that the three accounts of RIF need to be considered in order to fully explain the forgetting effect demonstrated by a RIF task. Separating the strong relation between Working Memory Capacity and Reasoning ability is a worthy endeavor, even though it could not be accomplished here.

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APPENDIX A

STIMULI USED IN RETRIEVAL INDUCED FORGETTING

Category	Exemplars
FILLER: Fuel	Oil, Steam, Wood, Coal, Electricity, Uranium
FILLER: Toys	Doll, Jacks, Rattle, Block, Car, Puzzle
Weapons	Sword, Rifle, Tank, Bomb, Pistol, Club
Fruits	Tomato, Strawberry, Lemon, Banana, Orange, Pineapple
Metals	Nickel, Brass, Gold, Iron, Aluminum, Silver
Trees	Elm, Spruce, Hickory, Birch, Dogwood, Redwood
Birds	Crow, Duck, Sparrow, Hawk, Woodpecker, Vulture
Relatives	Cousin, Nephew, Wife, Aunt, Husband, Son
Clothing	Socks, Pants, Tie, Jacket, Gloves, Vest
Diseases	Leukemia, Smallpox, Cancer, Measles, Flu, Cholera
Drinks	Bourbon, Ale, Whiskey, Vodka, Rum, Gin
Fish	Trout, Bluegill, Flounder, Catfish, Herring, Guppy
Insects	Beetle, Hornet, Mosquito, Roach, Fly, Grasshopper
Professions	Engineer, Nurse, Plumber, Accountant, Dentist, Farmer
Time	Century, Week, Month, Year, Day, Hour
Furniture	Lamp, Dresser, Footstool, Bed, Chair, Rug
Sports	Hockey, Swimming, Tennis, Wrestling, Track, Golf
Weather	Snow, Thunder, Cyclone, Hurricane, Lightning, Rain

Filler categories were presented for all participants as the first and last categories studied.

APPENDIX B

NOTICE OF IRB APPROVAL

ASU Knowledge Enterprise Development

EXEMPTION GRANTED

Zachary Shipstead
Social and Behavioral Sciences, School of
602/543-6932
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Dear Zachary Shipstead:

On 1/27/2015 the ASU IRB reviewed the following protocol:

Type of Review:	Initial Study
Title:	Retrieval Induced Forgetting as a Predictor of Fluid Intelligence
Investigator:	Zachary Shipstead
IRB ID:	STUDY00002115
Funding:	None
Grant Title:	None
Grant ID:	None
Documents Reviewed:	• Task Description.pdf, Category: Recruitment Materials; • Retrieval Induced Forgetting as a Predictor of Fluid Intelligence PROTOCOL.docx, Category: IRB Protocol; • Measures and materials to be viewed.pdf, Category: Recruitment Materials; • Short template consent form.pdf, Category: Consent Form;

The IRB determined that the protocol is considered exempt pursuant to Federal Regulations 45CFR46 (2) Tests, surveys, interviews, or observation on 1/27/2015.

In conducting this protocol you are required to follow the requirements listed in the INVESTIGATOR MANUAL (HRP-103).

Sincerely,