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The Effects of Acute Exercise on Retrieval Induced Forgetting

Walter Simpson

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By

Walter Myers Simpson III

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Approved By

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Advisor: Dr. Paul Loprinzi

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Reader: Dr. Allison Ford-Wade

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Reader: Dr. Hannah Allen

DEDICATION

This thesis is dedicated to those who helped guide me throughout this writing process, and any other individuals who helped structure, proof, and finalize this manuscript. Thank you all.

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ABSTRACT

Walter Myers Simpson III: The Effects of Acute Exercise on Retrieval Induced Forgetting (Under the direction of Dr. Paul Loprinzi)

Retrieval Induced Forgetting (RIF) is a type of active forgetting that may play beneficial and detrimental roles in long-term memory. The benefit of the retrieval of certain information is that information will become more readily available following subsequent retrieval; a concept termed the retrieval practice effect (RP). The detrimental effect of RIF may be that, upon the subsequent recall of certain information, related information may be inhibited from recall. The effects and mechanisms of RIF have remained a topic of debate among neuroscientists, psychologists, and other related scholars. The goal of this study was to evaluate the effects of acute exercise of varying intensities on RIF. Previous work indicates that those who regularly exercise have been observed to exhibit higher incidences of RIF. However, the present thesis experiment utilized an item-recognition assessment, as opposed to a cued-recall test that has been used in previous studies. The use of an item-recognition assessment should, in theory, better isolate the inhibition mechanism of RIF. A total of 50 participants were subjected to the RIF paradigm, including three phases: study, retrieval-practice, and final test. Participants were randomly assigned to a (1) control group with no exercise, (2) a moderate-intensity exercise group, or (3) a vigorous-intensity exercise group. After a five-minute rest period following exercise, all participants immediately began the RIF paradigm. Our results demonstrated a retrieval practice effect, but not a RIF effect. Furthermore, acute exercise did not influence retrieval practice or RIF. Further studies will be required to investigate the mechanisms of RIF and the factors involved in it’s occurrence.

PREFACE

I chose to write about this topic because of the lack of previous information explaining retrieval induced forgetting. Understanding the mechanism of retrieval induced forgetting may prove crucial in understanding the automatic processes involved in the retention of memory and forgetting. The applications of this and other related studies are numerous both in clinical and experimental settings. Retrieval induced forgetting has been a continuing topic of study in Dr. Paul Loprinzi's exercise and science lab, and much progress has been made in characterizing it.

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LIST OF ABBREVIATIONS

STM	short term memory
LTM	long term memory
RIF	retrieval induced forgetting
RP	retrieval practice effect
Rp+	practiced exemplars from practiced categories
Rp-	non-practiced exemplars from practiced categories
Nrp-	high-frequency non-practiced exemplars from non-practiced categories
Nrp+	low-frequency non-practiced exemplars from non-practiced categories

Chapter 1: RIF explained

1.1: Memory and Forgetting

The human brain is constantly filtering input from the environment around us, whether we are aware of such stimuli or not. The ability of our brains to retrieve information is limited by the amount of content stored and the time elapsed since the information was last retrieved. Our current knowledge of the human brain has led us to believe that there are stages of memory that differ in the coding and duration of stored information. These storage systems have been studied extensively in order to answer questions about the encoding processes and retrieval mechanisms.

Short term memory (STM) refers to what is currently, or was recently, in conscious thought. This system has the ability to store information over a brief period of time. This duration can be improved upon by the use of rehearsal techniques, which is the repetition of the coded material to keep it in conscious thought. In a classic study, STM was found to have a capacity of 5-9 items/chunks (Miller, 1956). With this limited capacity, information is easily lost from STM by decay or interference if not actively rehearsed or in active use.

Long term memory (LTM) refers to past experiences that are not currently in conscious thought, but that could be retrieved into consciousness. Long term memory does not require the rehearsal or the active use of information to achieve long term storage. Long term memory is believed to have an extensive capacity and a much longer duration than STM (Miller, 1956). This ability to store large quantities of information over long periods of time is thought to be due to the capacity of working memory[1] to process, encode, and categorize information based on the context cues and similarities between previously encoded material. The process of attaining new information impacts the physiology of certain nerve cells, called engram cells, creating memory traces (Davis & Zhong, 2017). These changes can affect the excitability of certain nerve cells to encourage an increase or decrease in nerve cell signaling and communication. Learning can initiate and maintain this neuronal communication by establishing new neural connections, or retract previously existing connections. A memory is the collection of all cellular manipulations due to the communication of neurons afflicted by the learning event; which are then able to influence future behaviors (Squire, 1987; Dudai, 2002; Davis, 2011).

Depending on the quality and context of a learned material, the memory can be strongly or weakly represented. There are two classes of forgetting, namely, passive and active. These categories differ in that active forgetting involves mechanisms for the intentional removal of unused memories, while passive forgetting is the unintentional loss of encoded information. Passive forgetting is believed to act through at least three different functional mechanisms: (1) the loss of context cues over time which complicates retrieval, (2) interference during retrieval from similar and possibly related memories, and (3) the natural decay of memory traces over prolonged time from biological material damage. The loss of context cues and retrieval interference may have left the memory actually intact, yet inaccessible. Active forgetting may also act through three different

[1] Working memory is a multicomponent executive function of the brain that manipulates information storage for increased and more elaborate cognitive utility (Baddeley & Hitch, 1974).

mechanisms. Interference-based forgetting states that competing information acquired prior (proactive) or after (retroactive) the intended lesson may further the decay of information. Motivated forgetting is the process of voluntarily stimulating cognitive mechanisms (e.g., executive control) in order to undermine memory traces, often employed following traumatic or unwanted experiences. Lastly, retrieval induced forgetting is the successful recall of certain aspects of a memory that suppress the retrieval of other related aspects (Anderson, Bjork, & Bjork, 1994). This type of active forgetting is the topic matter of this thesis.

1.2: What is Retrieval-Induced Forgetting

Retrieval-induced forgetting occurs as a consequence of memory retrieval (Bjork, 1975) (for a meta-analytical review, see Buchli, Miyatsu, Murayama, & Storm, 2014). When items are retrieved more frequently, they become easier to recall, while related information that was not regularly retrieved becomes more difficult to recall (Anderson, Bjork, & Bjork). In this sense, the human brain is emptying relatively unused memory traces. Retrieval-induced forgetting has been previously studied using a retrieval-practice paradigm. The typical paradigm employs three phases: study, retrieval-practice, and final test. Participants begin by studying a series of category-exemplar pairs which are presented individually for a few seconds. In the following retrieval-practice phase, participants are asked to retrieve half of the exemplars from half of the categories used during the initial study phase. They are then asked to complete a final test which requires the participant to try and recall all of the category-exemplar pairs used throughout the study. This paradigm exhibits four different categories of exemplars: (1) exemplars that receive retrieval practice from practiced categories (Rp+), (2) non-practiced exemplars from practiced categories (Rp-), (3) high-frequency non-practiced exemplars associated with non-practiced categories (Nrp-), and (4) low-frequency non-practiced exemplars from non-practiced categories (Nrp+). Two results are normally observed. First, practiced exemplars (Rp+) are retrieved more readily than non-practiced exemplars (Rp-) and those associated with non-practiced categories (Nrp items). Items that are regularly recalled experience a benefit of becoming more readily available for subsequent retrieval. The second common result is the observation of retrieval-induced forgetting (RIF). Retrieval-induced forgetting occurs when non-practiced exemplars from practiced categories (Rp-) are recalled at a significantly lower rate than high frequency non-practiced exemplars from non-practiced categories (Nrp-).

Retrieval-induced forgetting is an empirical phenomenon that has been repeatedly demonstrated, but there are disagreements on the theoretical mechanisms of this phenomenon. Proposed mechanisms have been discussed into two classes of thought: *Inhibition-based forgetting theories* and *competition-based forgetting theories.* According to the Inhibition theory perspective, when attempting to recall a target item from memory, many other items that are related to the same retrieval cue are also activated and cause competition. In order to successfully retrieve the target item, the co-activated non-targeted items must be inhibited. Simply put, inhibition is a cognitive function used to reduce interference from non-target items (Anderson, 2003). Some have argued that inhibition is a function of the frontal mediated executive-control processes, while others believe inhibition to be exercised locally in the medial temporal lobe (Norman et al., 2007). All inhibition-based theories typically agree that forgetting is a product of a process that dictates item retrieval by hindering the accessibility of interfering information. Competition theories, on the other hand, suggest that the recall of practiced (strengthened) items causes them to compete with non-strengthened items, thereby impeding non-strengthened items ability to be recalled (for various theories and reviews, see Anderson, 2003; Jonker, Seli, & MacLeod, 2013; Murayama et al., 2014; Storm & Levy, 2012; Verde, 2012).

When evaluating past studies, empirical data points to an inhibition-based forgetting mechanism of retrieval induced forgetting. However, researchers in agreement with the inhibition-based perspective also agree that competition could contribute to retrieval-induced forgetting, making the two classes of theories not as mutually exclusive as originally thought (Storm & Levy, 2012).

Chapter 2: Introduction

2.1: Our Study

As discussed, RIF is the consequence of memory retrieval (Bjork, 1975). Information that is related to items regularly recalled from memory stores becomes relatively more difficult to recall upon subsequent retrievals. This is thought to be a natural process that relieves the brain of unused memory traces that may influence other, more utilized, information. Another consequence of memory trace retrieval is the benefit of strengthening the ability to recall previously retrieved information. It is our objective to explore these consequences and how to manipulate the phenomenon of RIF.

In order to quantify the phenomenon of RIF, the retrieval-practice paradigm has been utilized in the past. This paradigm, as mentioned, includes the three phases: study, retrieval-practice, and final test. As discussed, a set of category-exemplar pairs are presented to an individual in the study phase. Following the study phase, half of the exemplars from half of the categories are presented as category-plus-two-letter-stem cues. Participants are asked to recall the cued items for multiple rounds. The final test phase requires the participant to attempt to recall as many of the exemplars from the entire study. The measured results are observed by recording the amount of practiced (Rp+) and non-practiced (Rp-) exemplars from practiced categories recalled compared to high frequency (Nrp-) and low frequency (Nrp+) non-practiced exemplars from non-practiced categories. Retrieval-induced forgetting (RIF) has been observed when non-practiced (Rp-) items are recalled at a significantly lower rate than high frequency non-practiced exemplars from non-practiced categories (Nrp-). The retrieval practice effect (RP) has occurred if practiced (Rp+) items are recalled more successfully than low frequency non-practiced (Nrp+) items.

Currently, there are two proposed theories explaining the mechanism of RIF, *inhibition-based forgetting* and *competition-based forgetting*. According to inhibition theory, RIF is the consequence of inhibitory mechanisms that occur during memory trace retrieval (Anderson, 2003). This is due to the idea that, during item retrieval, both target and non-target items are activated and inhibition is utilized to suppress the recall of the non-target items. This inhibition process is thought to not only encourage the retrieval of the target items, but also to deflate the ability to recall non-target items in later memory tests. Due to the empirical data collected in earlier studies, this inhibition-based forgetting mechanism has been given more support, but competition may also hold an impact. For example, individuals exhibiting higher levels of working memory capacity and executive control have been repeatedly observed to score higher in occurrences of RIF than individuals with lower working memory capacity and executive control (Aslan & Bäuml, 2011; Schilling, Storm, & Anderson, 2014; Storm & Bui, 2016). Recently, the observation of reduced blood flow in cortical areas correlated with non-practiced items has been reported during the RIF protocol (Wimber, Alink, Charest, Kriegeskorte, & Anderson, 2015). Studies have also shown that memorable items and items assumed to inflict competition during retrieval practice are more readily forgotten when compared to non-memorable items (Anderson et al., 1994; Reppa, Williams, Worth, Greville, & Saunders, 2017; Storm, Bjork, & Bjork, 2007). This inhibition process involved in executive control is debated to be heavily influenced by the activity of the prefrontal cortex. Research has correlated the obstruction of prefrontal cortex neural activity with the diminished or impaired occurrence of RIF (Stramaccia, Penolazzi, Altoe, & Galfano, 2017).

Minimal research has been conducted to determine the effects of exercise on forgetting, especially on RIF (Ferguson et al., 2018). More recently, a project (Padilla, Andres, & Bajo, 2018) revealed that physically active adults demonstrated significantly pronounced RIF when compared to sedentary individuals. This observation was assumed to be due to greater working memory. Cognitive inhibition has also been shown to improve when individuals are subject to acute exercise (Hsieh, Huang, Wu, Chang, & Hung, 2018). The assessment of fifty studies has been conducted in a meta-analysis by Oberste et al. (2019), which found that acute exercise held substantial influence over recorded levels of inhibition (Hedges' g for time-dependent measures = -0.26, 95% CI: -0.34, -0.18; Hedge's g for accuracy = 0.13; 95% CI: 0.04, 0.22). As mentioned, it is thought that the prefrontal cortex may play a crucial role in cognitive inhibition (Aron, 2007), and in turn, RIF. The idea that acute exercise may potentially aid cognitive inhibition ability may be explained by exercise increasing neural activity in the prefrontal cortex (Tsujii, Komatsu, and Sakatani, 2013). Shared affective mechanisms may also support the correlation between acute exercise and RIF. According to Ekkekakis, Parfitt, & Petruzzello (2011), moderate-intensity acute exercise may potentially give rise to a positive affective state. Furthermore, data collected from other studies has demonstrated that RIF is more likely to take place when participants are in a relatively good, rather than a depressed mood (Bäuml & Kuhbandner, 2007; Groome & Sterkaj, 2010; Storm & Jobe, 2012).

Currently, there is only one known study previously conducted that investigated the effects of acute exercise on RIF. This study evaluated if acute, moderate-intensity exercise could facilitate RIF (Cantrelle & Loprinzi, 2019). However, they did not observe an effect of acute exercise of RIF. The current thesis study is a follow-up to this previous experiment by Cantrelle and Loprinzi (2019). Unlike the Cantrelle and Loprinzi (2019) study, which utilized a cued-recall test, for this thesis, we altered the type of memory assessment utilized in the final test of the retrieval-practice paradigm. The design of the final test (e.g., category-cued, category-plus-stem cued-recall, cue-independent recall, recognition, implicit tasks) may influence an individual's ability to successfully exhibit RIF. It may also influence whether or not cognitive inhibition could be isolated as the primary mechanism behind RIF (Storm, 2018). This thesis study utilized an item-recognition assessment rather than using the category-plus-stem cued-recall test used in the previous experiment. According to some researchers, it is believed that item-recognition assessments, rather than processes such as occlusion and disruption of coding/retrieval strategies, may accurately quantify the occurrence of RIF caused by inhibitory effects (Gomez-Ariza, Lechuga, Pelegrina, & Bajo, 2005; Hicks and Starns, 2004). The effect of RIF due to the inhibition of Rp- items is assumed to also be observed in a recognition-based task due to the direct control of the availability of those items (Anderson and Spellman, 1995). Recognition tasks should isolate inhibition as the underlying mechanism of RIF because strength-dependent competition mechanisms would not foresee any occurrence of RIF in a recognition task (Raaijmakers & Shiffrin, 1981).

The primary objective of this experiment is to evaluate if acute exercise can facilitate RIF using an item recognition assessment. This, in theory, is expected to better isolate the inhibition mechanism of RIF.

Chapter 3: Methods

3.1: Study Design

A three-arm, parallel-group, randomized controlled intervention was utilized in our study. Participants were randomly placed into one of three groups: (1) control, (2) experimental moderate-intensity exercise, and (3) experimental vigorous-intensity exercise. The experimental groups engaged in exercise on a treadmill for a period of 20 minutes. The control group engaged in a seated task of medium level sudoku for 20 minutes. Following the 20 minutes of either exercise or sudoku, all three groups engaged in five minutes of rest. The memory assessment protocol, which immediately followed the rest period, utilized the same retrieval-induced forgetting protocol as found in previous studies (Anderson et al., 1994). The difference we introduced involves the final memory recall test, in which we used a recognition assessment rather than employing a category-plus-stem cued-recall assessment.

3.2: Participants

The present experiment included 50 participants, including 11, 22, and 17 in the control, moderate-intensity, and vigorous-intensity conditions, respectively. Participants were recruited by means of convenience-based, non-probability sampling. Recruitment took place by classroom announcements and word-of-mouth. Participants ranged in age from 18 to 25 years old, which included both undergraduate and graduate level students.

Participants were prohibited from participating if they:

Self-reported as a daily smoker (Jubelt et al., 2008; Klaming, Annese, Veltman, & Comijs, 2016); self-reported being pregnant (Henry & Rendell, 2007); exercised within 5 hours of testing (Labban et al., 2011); consumed caffeine within 3 hours of testing (Sherman, Buckley, Baena, & Ryan, 2016); had a concussion or head trauma within the past 30 days (Wammes, Good, & Fernandes, 2017); took marijuana or other illegal drugs within the past 30 days (Hindocha, Freeman, Xia, Shaban, & Curran, 2017); or were considered a daily alcohol user (>30 drinks/month for women; >60 drinks/month for men) (Le Berre, Fama, & Sullivan, 2017).

3.3: Exercise Protocol

The experimental groups were randomly assigned to one of two exercise conditions: (1) moderate-intensity and (2) vigorous-intensity. Both groups exercised at their assigned level of intensity for a period of 20 minutes. The 20 minute exercise protocol is parallel to previous work on investigating the effects of acute exercise on episodic memory (Frith, Sng, & Loprinzi, 2017). More recently, as observed in a meta-analysis, it was indicated that a single bout of exercise lasting 20 minutes was the most successful in amplifying inhibition relative to other exercise durations (Oberste et al., 2019). Immediately following the treadmill exercise, participants were seated in an enclosed computer lab and were instructed to play moderate-level sudoku for five minutes. The retrieval-practice paradigm assessment followed the rest period. As observed in meta-analytical research (Oberste et al., 2019), previous assessments found that there is no significant variation ($p > 0.41$) in inhibition when the cognitive assessment task took place within 15-minutes following exercise or an interlude longer than 15-minutes.

The two experimental groups varied by the intensity of exercise assigned. This intensity was recorded and assigned according to individual participants heart rate reserve (HRR). The moderate-intensity experimental group was to maintain exercise at an intensity that employed 50% of their HRR throughout the 20 minutes. While the vigorous-intensity experimental condition required participants to maintain exercise at an intensity employing 80% of their HRR throughout the 20 minutes. The thresholds of HRR utilized in the two conditions constitute moderate and vigorous-intensity exercise, respectively (Garber et al., 2011).

The HRR equation applied to this study to determine exercise intensity was: HRR = [(HRmax – HRrest) * % intensity] + HRrest. HRrest was recorded soon after the participants arrival, following an initial rest period of five minutes, using a chest-worn Polar heart rate monitor. HRmax was estimated by the formula: 220 - age.

3.4: Control Protocol

Participants randomly allocated to the control protocol, in relation to previous studies (McNerney & Radvansky, 2015), completed a medium-level, online operated, sudoku puzzle for 25 minutes. This period includes the time allotted for the exercise condition and the 5 minute rest period. The online puzzle can be found at: https://www.websudoku.com/. Previous research has indicated that sudoku may not hold any influence over memory or cognitive functions, and for this reason, may be used as a satisfactory control condition (Blough et al., 2019).

3.5: Memory Assessment

As previously mentioned, our study utilized the standard RIF protocol. This protocol employs three phases: (1) a study phase, (2) a retrieval-practice stage, and (3) a final recall phase (Anderson et al., 1994). Our recognition test employed 144 items, 72 of which were be studied by participants (6 items from each of the 12 categories) and 72 lures (also 6 items from the 12 categories); all of which maintained moderate-to-high frequency. The 12 categories were counterbalanced between the participants, meaning half of the sample size would study items from a certain 6 categories while the other half of participants studied items from the remaining 6 categories. The study phase required participants to encode 72 category-exemplar word pairs. The word pairs were displayed one at a time, for a period of 3.5 seconds each. Following the study phase, participants immediately began the retrieval practice. This practice involved participants being cued via a category-plus-two-letter-stem cue of the exemplar. Retrieval practice presented participants with cues of half of the word pairs from half of the categories for a total of 4 rounds of the same cues. If the participant was able to recall the cued exemplar, in a 10 second period, during the retrieval practice phase, they would verbally announce the exemplar. The final recognition test employed participants to respond via typing Y (yes) or N (no) for all of the items presented during the study, those studied (old) and not (new), respectively. Each item was presented for recognition one at a time at a self-pace. Details of the items used follows.

The 144 items were presented in an order of blocked randomization, allowing one exemplar to be tested from each of the 12 categories. Seventy-two category-exemplar pairs were employed from earlier research (Storm & Bui, 2016). These pairs included 6 items from 12 categories: clothing, drinks, fish, flavors, fruits, insects, metals, professions, sports, tools, trees, and weapons. Half of the exemplars from each category were high-frequency, while the other half being low-frequency. So, in summary, there were 36 high-frequency (Rp-/Nrp-) and 36 low-frequency (Rp+/Nrp+) items presented per participant. The final recognition test randomly presented the non-practiced high frequency items from practiced (Rp-) and non-practiced (Nrp-) categories (and lures) in the first half of the test. While the practiced low-frequency items from practiced (Rp+) and non-practiced categories (Nrp+) (and lures) were tested in the second half. This order of the final recognition assessment has commonly been employed in the study of RIF and has the benefit of controlling for output interference (Murayama et al., 2014). Retrieval induced forgetting was quantified by subtracting the amount of recalled Rp- items from the amount of recalled Nrp- items. The retrieval-practice effect was quantified by subtracting the amount of recalled Nrp+ items from the amount of recalled Rp+ items.

3.6: Statistical Analyses

All of the statistical analyses were computed using JASP (v. 0.12.2.0). A 2 (Rp- vs. Nrp-) x 3 (Control vs. Moderate-Intensity vs. Vigorous Intensity) RM-ANOVA was employed on the recall of the high-frequency items to assess RIF. A 2 (Rp+ and Nrp+) x 3 (Control vs. Moderate-Intensity vs. Vigorous-Intensity) RM-ANOVA was employed on the recall of the low-frequency items to assess RP.

Chapter 4: Results

4.1: Data

Table 1 displays the demographic characteristics of the sample, across each of the experimental conditions. Participants, on average, were 19.62 (SD = 1.537) years of age, with the majority (72%) of the sample being male. There were no statistically significant differences in these demographic parameters across the three conditions, all p's > .05.

Table 1: Sample Population Characteristics

Variable	Control	Moderate-Intensity	Vigorous-Intensity
N	11	22	17
Age, Mean years	19.63	19.36	19.94
Gender, % Men	72.7%	68.1%	76.5%
Race, % White	100%	100%	88%
MVPA, mean min/week	196.82	197.95	165.00

MVPA, Moderate-to-vigorous physical activity

Table 2 displays the memory results for the control condition and each of the experimental conditions. In a 2 (Rp- vs. Nrp-) x 3 (Control vs. Moderate-Intensity vs. Vigorous-Intensity) RM-ANOVA assessing RIF. We did not observe a main effect for RIF, $F(1, 47) = .27$, $p = .60$, $\eta^2 = .001$, main effect for group, $F(2, 47) = 1.12$, $p = .34$, $\eta^2 = .04$, or a RIF x group interaction, $F(2, 47) = .42$, $p = .65$, $\eta^2 = .01$.

The red data included in Table 2 exhibits the recall performance of the low-frequency exemplars from the final recognition assessment across all three conditions. These exemplars were used to measure the effects of RP on subsequent memory. On the other hand, the data in black ink included in Table 2 exhibits the recall performance of the high-frequency exemplars from the final recognition assessment across all three conditions. These high-frequency exemplars were used to measure the effects of RIF on subsequent memory.

Table 2: Descriptive Statistics

	Nrp+			Nrp-			Rp+			Rp-		
	Control	Moderate	Vigorous	Control	Moderate	Vigorous	Control	Moderate	Vigorous	Control	Moderate	Vigorous
Valid	11	22	17	11	22	17	11	22	17	11	22	17
Missing	0	0	0	0	0	0	0	0	0	0	0	0
Mean	0.763	0.777	0.761	0.737	0.729	0.784	0.885	0.897	0.926	0.725	0.737	0.766
Standard Deviation	0.088	0.117	0.119	0.105	0.114	0.111	0.078	0.076	0.056	0.099	0.112	0.094
Minimum	0.640	0.500	0.470	0.500	0.500	0.560	0.720	0.690	0.780	0.580	0.500	0.640
Maximum	0.860	0.940	0.920	0.860	0.920	0.940	0.970	1.000	1.000	0.890	0.920	0.920

Note*: The use of red colored text was utilized to make the data more easily distinguished.

In a 2 (Rp+ vs. Nrp+) x 3 (Control vs Moderate-Intensity vs. Vigorous-Intensity) RM-ANOVA assessing retrieval practice, we observed a main effect for retrieval practice, $F(1, 47) = 75.62$, $p < .001$, $\eta^2 = .34$, but no main effect for group, $F(2, 47) = .21$, $p = .80$, $\eta^2 = .004$, or a retrieval practice x group interaction, $F(2, 47) = .98$, $p = .38$, $\eta^2 = .009$. **Figure 1** displays the retrieval practice effect across the three experimental groups.

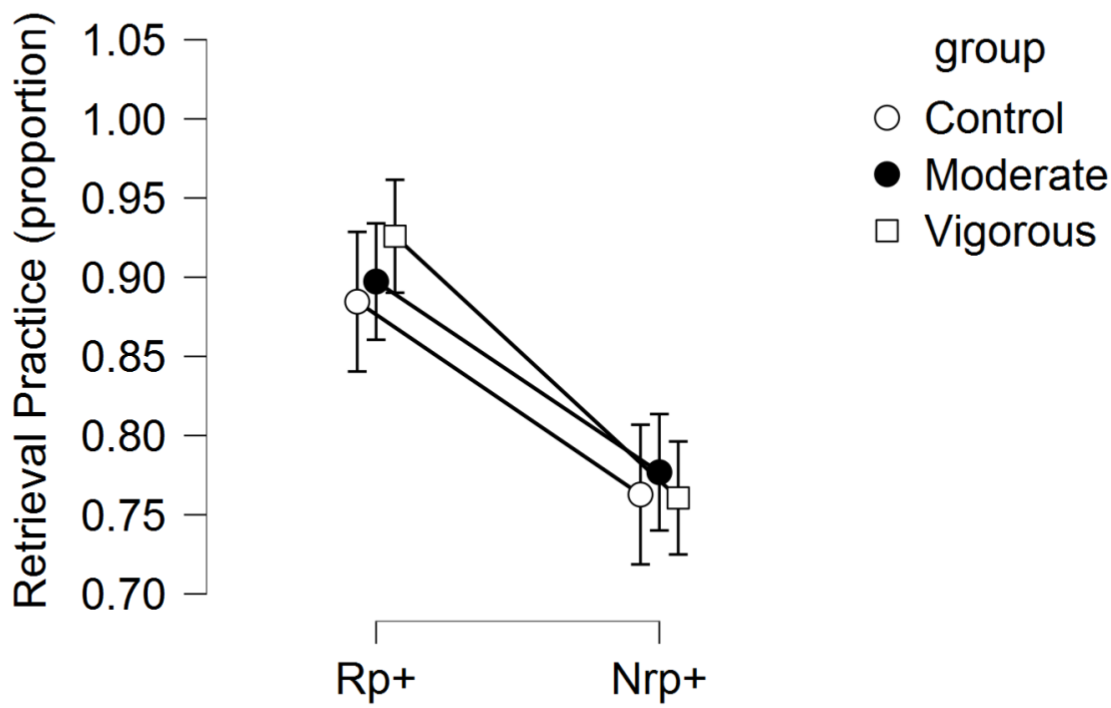

Figure 1: Retrieval practice results across the three experimental conditions. Error bars represent 95% confidence intervals.

Chapter 5: Discussion

5.1: Our Findings:

Previous studies have demonstrated that acute exercise may enhance memory function. However, acute exercise has also been observed to initiate certain aspects of forgetting by facilitating inhibitory-based mechanisms. If RIF is the product of inhibitory mechanisms during retrieval practice, increased cognitive inhibition via acute exercise may lead to increased forgetting of non-practiced items. The results of this study, however, do not support this hypothesis.

We were unable to observe any RIF effect in our study. Meaning that the average number of Rp- items recalled did not surpass the amount of Nrp- items recalled. Furthermore, our retrieval practice session did not reduce forgetting of the Rp- items, opposing what was expected. As such, we were unable to demonstrate an effect of acute exercise, at neither moderate nor vigorous-intensities, on RIF because we were unable to observe any RIF effect at all.

On the other hand, we did observe a significant main effect for RP, but no main effect for group or retrieval practice x group interaction was observed. Meaning that, on average, more practiced Rp+ items were recalled compared to the Nrp+ items, but acute exercise did not alter this effect.

In comparison to past studies, the use of the item recognition test may have been detrimental to the expected RIF effect. In a previous study using a category-plus-stem cued-recall assessment, a significant main effect for RIF (F (1, 222) = 76.32, $p < .001$, $\eta^2 = .07$) was found (Loprinzi, 2019). This could lead to another possible explanation for the loss of a significant effect for RIF in this study; the use of recognition assessments in the retrieval practice paradigm may follow competition-based mechanisms. If RIF was attributed to the inhibition of the Rp- items, then the effect should have been observed in a recognition assessment because of the direct influence of item availability (Anderson and Spellman, 1995). Because no RIF effect was observed while using the recognition test, an alternative explanation of the mechanism behind RIF may be entertained. Interference theories that use strength-dependent competition mechanisms would predict no RIF in recognition assessments (Raaijmakers and Shiffrin, 1981). The absence of a significant RIF effect in this study may indicate that interference theories' estimations of competition-based mechanisms influencing RIF may be more accurate.

5.2: Strengths and Limitations

This study had a sample size of 50 individuals. This is a relatively small sample size, meaning that the absence of a significant RIF effect may be due to inadequate statistical power. This study is very similar to previous studies in terms of the methods used, statistical analysis, and kept the retrieval practice paradigm authentic. The only major variable manipulated was the use of a recognition test. This means that the results of this study, as compared with similar studies, must be a result of this manipulation.

5.3: Future Recommendations

The use of a larger sample size could ensure that inadequate power would not be the cause of our null RIF effects. Future work on this topic is absolutely required in order for an adequate understanding of the mechanism(s) influencing RIF. This is especially true concerning the effects of different memory assessments influencing the potential effect of acute exercise on RIF. As previously stated, the two classes of theory behind the mechanisms of RIF (Inhibition and Competition theories) may not be as mutually exclusive as once thought. In future studies, perhaps a neutral approach to measure RIF should be drawn, one that does not specify inhibition or competition but rather combines the two classes of thought. Further testing using various other assessments would greatly influence our knowledge of executive functioning and memory. Another potential variable that could be assessed by future studies is the time between exercise and the paradigm. This study used a rest period of 5 minutes before the memory task which was modeled after previous studies work showing that 5 minutes would allow for any potential exercise-induced enhancement effects on memory (Frith et al., 2017). Theoretically, these potential enhancement effects could be transient, meaning the 5-minute rest period could have impaired or diminished any exercise-induced effects. Perhaps supplying the memory assessment during exercise could influence the level of cognitive inhibition and furthermore the effect of RIF. This design would control for any potential differences in encoding between individuals and would also identify differences in retrieval practice. A limitation to this design, however, is that exercise could implicate a context-change manipulation, a variable that could have influence whether or not RIF is observed independently of the impact of exercise on executive control.

5.4: Conclusion

In conclusion, this present study demonstrated a significant retrieval practice effect, but no significant RIF effect. The inability to observe a RIF effect also led to the inability to make any correlations between acute exercise intensity and RIF. Acute exercise of neither moderate nor vigorous intensity was found to play any role in manipulating cognitive inhibition (and therefore held no role in eliciting a retrieval practice effect nor retrieval induced forgetting effect). The use of a recognition test exhibiting no RIF results may potentially be evidence in support of the competition theories of RIF mechanisms. Further investigation is recommended in order to determine the potential influence of the type of memory assessment used on the effects of acute exercise on RIF.

BIBLIOGRAPHY

Anderson, M. C. (2003). Rethinking interference theory: Executive control and the mechanisms of forgetting. *Journal of Memory and Language, 49*, 415-445.

Anderson, M. C., Bjork, R. A., & Bjork, E. L. (1994). Remembering can cause forgetting: retrieval dynamics in long-term memory. *J Exp Psychol Learn Mem Cogn, 20*(5), 1063-1087. doi: 10.1037//0278-7393.20.5.1063

Anderson, M. C., & Green, C. (2001). Suppressing unwanted memories by executive control. *Nature, 410,* 131-134.

Anderson, M. C. & Spellman, B. A. (1995). On the satus of inhibitory mechanisms in cognition: Memory retrieval as a model case. *Psychological Review*, 102, 68-100.

Aron, A. R. (2007). The neural basis of inhibition in cognitive control. *Neuroscientist,* 13(3), 214-228.

Aslan, A., & Bauml, K. H. (2011). Individual differences in working memory capacity predict retrieval-induced forgetting. *J Exp Psychol Learn Mem Cogn, 37*(1), 264-269. doi: 10.1037/a0021324

Baddeley, A., and Hitch, G. (1974). Working memory. *Psychol. Learn. Motiv*. 8, 47-89.

Ball, T. J., Joy, E. A., Gren, L. H., & Shaw, J. M. (2016). Concurrent Validity of a Self-Reported Physical Activity "Vital Sign" Questionnaire With Adult Primary Care Patients. *Prev Chronic Dis, 13*, E16. doi: 10.5888/pcd13.150228

Bauml, K. H., & Kuhbandner, C. (2007). Remembering can cause forgetting--but not in negative moods. *Psychol Sci, 18*(2), 111-115. doi: 10.1111/j.1467-9280.2007.01857.x

Bjork, R. A. (1989). Retrieval inhibition as an adaptive mechanism in human memory. In H. L. Roediger & F. I. M. Craik (Eds.), *Varieties of memory and consciousness: Essays in honour of Endel Tulving* (pp. 309-330). Hillsdale, NJ: Lawrence Erlbaum Associates.

Blough, J., & Loprinzi, P. D. (2019). Experimental manipulation of psychological control scenarios: Implications for exercise and memory research. *Psych, 1*(1), 279-289.

Cantrelle, J., & Loprinzi, P. D. (2019). Exercise and retrieval-induced forgetting. *Psych, 1*(1), 405-411.

Chang, Y. K., Chu, C. H., Wang, C. C., Wang, Y. C., Song, T. F., Tsai, C. L., & Etnier, J. L. (2015). Dose-response relation between exercise duration and cognition. *Med Sci Sports Exerc, 47*(1), 159-165. doi: 10.1249/MSS.0000000000000383

Chang, Y. K., Labban, J. D., Gapin, J. I., & Etnier, J. L. (2012). The effects of acute exercise on cognitive performance: a meta-analysis. *Brain Res, 1453*, 87-101. doi: 10.1016/j.brainres.2012.02.068

Davis, R. L., & Zhong, Y. (2017). The Biology of Forgetting-A Perspective. *Neuron, 95*(3), 490-503. doi: 10.1016/j.neuron.2017.05.039

Edwards, M. K., Addoh, O., Herod, S. M., Rhodes, R. E., & Loprinzi, P. D. (2017). A Conceptual Neurocognitive Affect-Related Model for the Promotion of Exercise Among Obese Adults. *Curr Obes Rep, 6*(1), 86-92. doi: 10.1007/s13679-017-0244-0

Ekkekakis, P., Parfitt, G., & Petruzzello, S. (2011). The pleasure and displeasure people feel when they exercise at different intensities: Decennial update and progress towards a tripartite rational for exercise intensity prescription. *Sports Medicine*, 41(8), 641-671.

El-Sayes, J., Harasym, D., Turco, C. V., Locke, M. B., & Nelson, A. J. (2019). Exercise-Induced Neuroplasticity: A Mechanistic Model and Prospects for Promoting Plasticity. *Neuroscientist, 25*(1), 65-85. doi: 10.1177/1073858418771538

Etnier, J. L., Wideman, L., Labban, J. D., Piepmeier, A. T., Pendleton, D. M., Dvorak, K. K., & Becofsky, K. (2016). The Effects of Acute Exercise on Memory and Brain-Derived Neurotrophic Factor (BDNF). *J Sport Exerc Psychol, 38*(4), 331-340. doi: 10.1123/jsep.2015-0335\

Fawcett, J.M. & Hulbert, J.C. (2020). The many faces of forgetting: Toward a constructive view of forgetting in everday life. *Journal of Applied Research in Memory and Cognition*, 9(1), 1-18.

Ferguson, L., Cantrelle, J., & Loprinzi, P. D. (2018). Experimental effects of exercise on forgetting. *OBM Integrative and Complementary Medicine, 3*(4), 034. doi: doi:10.21926/obm.icm.1804034

Frith, E., Sng, E., & Loprinzi, P. D. (2017). Randomized controlled trial evaluating the temporal effects of high-intensity exercise on learning, short-term and long-term memory, and prospective memory. *Eur J Neurosci*, *46*(10), 2557-2564. doi: 10.1111/ejn.13719

Garber, C.E., Blissmer, B. Deschenes, M.R., Franklin, B.A., Lamonte, M.J., Lee, I.M., Nieman, D.C., Swain, D.P. (2011). The American College of Sports Medicine stand. Quantitiy and quality of exercise for developing and maintaining cardiorespiratory fitness, musculoskeletal, and neuromotor fitness in apparently healthy adults: Guidance for prescribing exercise. *Medicine & Science in Sports & Exercise*, *43*, 1334-1359.

Gomez-Ariza, C.J., Lechuga, M.T., Pelegrina, S., and Bajo, M.T. (2005). Retrieval-induced forgetting in recall and recognition of thematically related and unrelated sentences. *Memory and Cognition*, 33(8), 1431-1441.

Groome, D. H., & Sterkaj, F. (2010). Retrieval-induced forgetting and clinical depression. *Cognition and Emotion*, *24*(1), 63-70.

Henry, J. D., & Rendell, P. G. (2007). A review of the impact of pregnancy on memory function. *J Clin Exp Neuropsychol*, *29*(8), 793-803. doi: 10.1080/13803390701612209

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

Hindocha, C., Freeman, T. P., Xia, J. X., Shaban, N. D. C., & Curran, H. V. (2017). Acute memory and psychotomimetic effects of cannabis and tobacco both 'joint' and individually: a placebo-controlled trial. *Psychol Med*, 1-12. doi: 10.1017/S0033291717001222

Hsieh, S. S., Huang, C. J., Wu, C. T., Chang, Y. K., & Hung, T. M. (2018). Acute Exercise Facilitates the N450 Inhibition Marker and P3 Attention Marker during Stroop Test in Young and Older Adults. *J Clin Med, 7*(11). doi: 10.3390/jcm7110391

Jonker, T. R., Seli, P., & MacLeod, C. M. (2013). Putting retrieval-induced forgetting in context: an inhibition-free, context-based account. *Psychol Rev, 120*(4), 852-872. doi: 10.1037/a0034246

Jubelt, L. E., Barr, R. S., Goff, D. C., Logvinenko, T., Weiss, A. P., & Evins, A. E. (2008). Effects of transdermal nicotine on episodic memory in non-smokers with and without schizophrenia. *Psychopharmacology (Berl), 199*(1), 89-98. doi: 10.1007/s00213-008-1133-8

Klaming, R., Annese, J., Veltman, D. J., & Comijs, H. C. (2016). Episodic memory function is affected by lifestyle factors: a 14-year follow-up study in an elderly population. *Neuropsychol Dev Cogn B Aging Neuropsychol Cogn*, 1-15. doi: 10.1080/13825585.2016.1226746

Labban, J. D., & Etnier, J. L. (2011). Effects of acute exercise on long-term memory. *Res Q Exerc Sport, 82*(4), 712-721. doi: 10.1080/02701367.2011.10599808

Labban, J. D., & Etnier, J. L. (2018). The Effect of Acute Exercise on Encoding and Consolidation of Long-Term Memory. *J Sport Exerc Psychol, 40*(6), 336-342. doi: 10.1123/jsep.2018-0072

Le Berre, A. P., Fama, R., & Sullivan, E. V. (2017). Executive Functions, Memory, and Social Cognitive Deficits and Recovery in Chronic Alcoholism: A Critical Review to Inform Future Research. *Alcohol Clin Exp Res*. doi: 10.1111/acer.13431

Levy, B. J., & Anderson, M. C. (2002). Inhibitory processes and the control of memory retrieval. *Trends in Cognitive Sciences, 6*, 299-305.

Loprinzi, P. D. (2018). Intensity-specific effects of acute exercise on human memory function: considerations for the timing of exercise and the type of memory. *Health Promot Perspect, 8*(4), 255-262. doi: 10.15171/hpp.2018.36

Loprinzi, P. D., Blough, J., Crawford, L., Ryu, S., Zou, L., & Li, H. (2019). The temporal effects of acute exercise on episodic memory function: Systematic review with meta-analysis. *Brain Sciences, 9*(4), 87.

Loprinzi, P. D., Edwards, M. K., & Frith, E. (2017). Potential avenues for exercise to activate episodic memory-related pathways: a narrative review. *Eur J Neurosci, 46*(5), 2067-2077. doi: 10.1111/ejn.13644

McNerney, M. W., & Radvansky, G. A. (2015). Mind racing: The influence of exercise on long-term memory consolidation. *Memory, 23*(8), 1140-1151. doi: 10.1080/09658211.2014.962545

Murayama, K., Miyatsu, T., Buchli, D., & Storm, B. C. (2014). Forgetting as a consequence of retrieval: a meta-analytic review of retrieval-induced forgetting. *Psychol Bull, 140*(5), 1383-1409. doi: 10.1037/a0037505

Oberste, M., Javelle, F., Sharma, S., Joisten, N., Walzik, D., Bloch, W., Zimmer, P. (2019). Effects and moderators of acute aerobic exercise on subsequent interference control: A systematic review and meta-analysis. *Frontiers in Psychology*, 10, 2616.

Padilla, C., Andres, P., & Bajo, T. (2018). Improving Memory Inhibition: A Study of Retrieval Induced Forgetting, Executive Control, and Chronic Aerobic Exercise. *Front Behav Neurosci, 12*, 318. doi: 10.3389/fnbeh.2018.00318

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

Rathore, A. & Lom, B. (2017). The effects of chronic and acute physical activity on working memory performance in healthy participants: A systematic review with meta-analysis of randomized controlled trials. *Systematic Reviews*, 6, 124.

Reppa, I., Williams, K. E., Worth, E. R., Greville, W. J., & Saunders, J. (2017). Memorable objects are more susceptible to forgetting: Evidence for the inhibitory account of retrieval-induced forgetting. *Acta Psychol (Amst), 181*, 51-61. doi: 10.1016/j.actpsy.2017.09.012

Román, P., Soriano, M. F., Gómez-Ariza, C. J., & Bajo, M. T. (2009). Retrieval-induced forgetting and executive control. *Psychological Science, 20,* 1053-1058.

Rupprecht, J. & Bäuml, K-H. T. (2016). Retrieval-induced forgetting in item recognition: Retrieval specificity revisited. *Journal of Memory and Language*, 86, 97-118.

Schilling, C. J., Storm, B. C., & Anderson, M. C. (2014). Examining the costs and benefits of inhibition in memory retrieval. *Cognition, 133*(2), 358-370. doi: 10.1016/j.cognition.2014.07.003

Sherman, S. M., Buckley, T. P., Baena, E., & Ryan, L. (2016). Caffeine Enhances Memory Performance in Young Adults during Their Non-optimal Time of Day. *Front Psychol, 7*, 1764. doi: 10.3389/fpsyg.2016.01764

Storm, B. C. (2011). The benefit of forgetting in thinking and remembering. *Current Directions in Psychological Science, 20,* 291-295.

Storm, B. C. (2018). Measures of Forgetting. In H. Otani & B. L. Schwartz (Eds.), *Handbook of Research Methods in Human Memory* (pp. 36-49). New York: Routledge.

Storm, B. C., Angello, G., Buchli, D. R., Koppel, R. H., Little, J. L., & Nestojko, J. F. (2015). A review of retrieval-induced forgetting in the contexts of learning, eye-witness memory, social cognition, autobiographical memory, and creative cognition. *Psychology of Learning and Motivation*, *62*, 141-194.

Storm, B. C., Bjork, E. L., & Bjork, R. A. (2007). When intended remembering leads to unintended forgetting. *Q J Exp Psychol (Hove), 60*(7), 909-915. doi: 10.1080/17470210701288706

Storm, B. C., & Bui, D. C. (2016). Retrieval-practice task affects relationship between working memory capacity and retrieval-induced forgetting. *Memory*, *24*(10), 1407-1418. doi: 10.1080/09658211.2015.1117640

Storm, B. C., & Jobe, T. A. (2012). Retrieval-induced forgetting predicts failure to recall negative autobiographical memories. *Psychol Sci*, *23*(11), 1356-1363. doi: 10.1177/0956797612443837

Storm, B. C., & Levy, B. J. (2012). A progress report on the inhibitory account of retrieval-induced forgetting. *Mem Cognit, 40*(6), 827-843. doi: 10.3758/s13421-012-0211-7

Stramaccia, D. F., Penolazzi, B., Altoe, G., & Galfano, G. (2017). TDCS over the right inferior frontal gyrus disrupts control of interference in memory: A retrieval-induced forgetting study. *Neurobiol Learn Mem, 144*, 114-130. doi: 10.1016/j.nlm.2017.07.005

Tillman, B., & Loprinzi, P. D. (2019). The experimental effects of acute exercise intensity on episodic memory and working memory function. *Journal of Neurobehavioral Sciences, 6*(1), 12-20.

Tsujii, T., Komatsu, K. & Sakatani, K. (2013). Acute effects of physical exercise on prefrontal cortex activity in older adults: A functional near-infrared spectroscopy study. *Advances in Experimental Medicine and Biology*, 765, 293-298.

Verde, M. F. (2012). Retrieval-induced forgetting and inhibition: A critical review. In B. H. Ross (Ed.), *The Psychology of Learning and Motivation* (Vol. 56, pp. 47-80): Elsevier Academic Press.

Wammes, J. D., Good, T. J., & Fernandes, M. A. (2017). Autobiographical and episodic memory deficits in mild traumatic brain injury. *Brain Cogn, 111*, 112-126. doi: 10.1016/j.bandc.2016.11.004

Wimber, M., Alink, A., Charest, I., Kriegeskorte, N., & Anderson, M. C. (2015). Retrieval induces adaptive forgetting of competing memories via cortical pattern suppression. *Nat Neurosci, 18*(4), 582-589. doi: 10.1038/nn.3973

Wu, J. Q., Peters, G. J., Rittner, P., Cleland, T. A., & Smith, D. M. (2014). The hippocampus, medial prefrontal cortex, and selective memory retrieval: evidence from a rodent model of the retrieval-induced forgetting effect. *Hippocampus, 24*(9), 1070-1080. doi: 10.1002/hipo.22291