Spring 5-7-2022

The Effects of Acute Exercise Intensity on Retrieval-induced Forgetting

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by
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A thesis submitted to the faculty of The University of Mississippi in partial fulfillment of the requirements of the Sally McDonnell Barksdale Honors College

Oxford, MS

May 2022

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ACKNOWLEDGEMENTS

First and foremost, I wish to express extreme gratitude to Dr. Paul D. Loprinzi who has served as my research advisor throughout my time at the University of Mississippi. His overwhelming support and guidance throughout this thesis process have been an invaluable part in furthering my academic career and shaping the person that I am today. Also, I would like to thank my fellow researchers Jeremiah Blough, Emma Cochran, Windfield Swetman, Rylie Mangold, Lauren Fuglaar, and Sierra Petty for assisting me in the recruitment of participants and the collection of data. Furthermore, I would like to thank the members of my thesis committee, Dr. Allison Ford-Wade and Dr. Victoria Zigmont for their expert advice and assessment of my thesis. Lastly, I would like to thank my mother and father for all the sacrifices that they have made for me, and for their constant support not only during this thesis process, but throughout my entire life. Thank you again to everyone who has helped me, I have been incredibly blessed to have such amazing individuals by my side, and there is no doubt that this wouldn't have been possible without all of you.

ABSTRACT

Geoffrey Bryan Rosquillo Reliquias: The Effects of Acute Exercise Intensity on Retrieval-induced Forgetting (Under the direction of Dr. Paul Loprinzi)

Previous research has indicated that aspects of cognitive inhibition may be enhanced after engaging in acute exercise. Notably, cognitive inhibition has been theorized as a potential mechanism for a form of active forgetting known as *retrieval-induced forgetting* (RIF). Given that cognitive inhibition may explain the RIF phenomenon, and is also influenced by exercise, it is plausible that acute exercise may directly influence RIF. To our knowledge, only one study has examined whether acute exercise has an effect on RIF. The findings of that study did not find a statistically significant effect for RIF; however, we believe that the rather small sample size (N=40) may have limited the statistical power to detect a significant effect. Therefore, the present thesis (N=158) aims to address that limitation by increasing the sample size to a degree that would improve the potential for statistical significance to be reached. The methods in this thesis were similar to that of the past experiment, however, the exercise protocol was positioned after the cued-recall test, as opposed to before. The findings of this thesis demonstrated that (1) RIF was reliably induced with a cued-recall based task and (2) acute exercise preserved RIF. Therefore, an exercise-RIF relationship may exist when recall occurs before exercise, as demonstrated by the preservation of RIF after acute exercise.

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Chapter 1: Background

1.1: Types of Forgetting

The act of forgetting a set of information is a relatively innocuous occurrence in our lives, and though frustrating at times, little consideration is put into how it occurs. Nevertheless, forgetting is an intricate construct involving a myriad of neurological activity occurring both passively and actively. The passive mechanisms of forgetting have been theorized by various researchers as the gradual loss of engrams, or memory traces, caused by volatile biological components, contextual losses during the acquisition and the consolidation of information, and the obtrusion of related memories during the acquisition of a desired one (Davis & Zhong, 2017). These mechanisms are considered "passive" as the current psychological viewpoint considers the brain incapable of active degradation of memory substrates. Conversely, the active mechanisms of forgetting are deemed "active" due to their ability to be triggered by external or internal stimuli. Active forgetting can be classified into three types: interference-based forgetting (proactive and retroactive), motivated forgetting, and retrieval-induced forgetting. Interference-based forgetting occurs when new information is acquired before (proactive) or after (retroactive) a learning event, thus causing an inhibition of one's memory process. Motivated forgetting describes the suppression of memories, typically ones that invoke negative feelings, that occurs under one's direct control. Finally, retrieval-induced forgetting (RIF) refers to the retrieval of select items of a category, which in turn attenuates the retrieval of non-practiced items of that same category (Davis & Zhong, 2017). Further details on RIF will be explained in the following section.

1.2: Understanding Retrieval-Induced Forgetting

As a result of the dynamic nature of memory cognition, retrieving information modifies its availability within one's memory both positively and negatively. Specifically, items practiced more frequently become easier to recall (positive), while non-practiced items are more difficult to recall (negative). The less favorable, negative outcome associated with retrieval is known as RIF (Bjork, 1975) (for a meta-analytical review, see Buchli, Miyatsu, Murayama, & Storm, 2014). When studying RIF, it is standard to utilize a retrieval-practice paradigm consisting of a study, retrieval practice, and test phase. During the initial (study) phase of this paradigm, the participant studies a series of category-exemplar pairs presented briefly in a semi-randomized order. Afterwards, during the following (retrieval practice) phase, the participant will undergo several rounds of retrieval practice where they retrieve half of the exemplars from half of the categories. Lastly, during the final (test) phase, participants are evaluated on their ability to recall (or retrieve) the exemplars presented during the study phase. The aforementioned paradigm involves three variables: practiced exemplars from practiced categories (Rp+), non-practiced exemplars from practiced categories (Rp-), and non-practiced exemplars from non-practiced categories (Nrp). The phenomenon of RIF occurs when Rp- items have a lower recall rate than Nrp items.

Despite RIF being a widely researched area, its theoretical mechanisms bring about differing opinions amongst researchers. Varying theories exist to explain the phenomenon, however, the two most prominently discussed are the *inhibition-based* *forgetting theories* and *competition-based theories*. The inhibition theory proposes that when an individual attempts to retrieve a particular item from memory, it also causes other related items to be activated. Therefore, an inhibitory process reduces the interference of non-target related items to ensure successful recall of the target item (Anderson, 2003). Within the inhibition theory, differing theoretical accounts exist to explain its processes. Some of these accounts argue that the inhibitory mechanism is performed locally within the medial temporal lobe of the brain, while others cite the mechanism to be more executively controlled by the prefrontal cortex. Nevertheless, these perspectives share the common viewpoint that forgetting is a product of an adaptive process that aims to inhibit interfering information so that the retrieval of target information occurs effectively. Conversely, supporters of the competition theory argue that these inhibitory mechanisms are inconsequential in explaining RIF. They argue that RIF occurs as a result of practiced items being more accessible than non-practiced items. Specifically, these practiced items received strengthening during retrieval practice, which in turn, impaired the retrieval of non-strengthened items (for various reviews and perspectives, see Anderson, 2003; Jonker, Seli, & MacLeod, 2013; Murayama et al., 2014; Storm & Levy, 2012; Verde, 2012).

As previously stated, differing theories exist regarding the theoretical mechanisms of RIF. It is important to note, however, that though a researcher may reject one form of the inhibition or competition-based theories, it is not an absolute rejection of all other forms of the respective theories. Notably, inhibition-based theorists have even conceded that it is plausible for competition to play a role in RIF, arguing that the two theories are not necessarily mutually exclusive. (Storm & Levy, 2012). Therefore, it is apparent that a more refined version of these two theoretical accounts is imperative in order to ultimately understand the true mechanisms of RIF.

The present thesis considers inhibition as a primary mechanism of RIF. As will be discussed, acute exercise has been shown to influence inhibition, providing justification for a potential role of acute exercise in influencing RIF. This potential link between acute exercise and RIF is the central focus of this thesis.

Chapter 2: Introduction

Emerging work provides empirical support for the inhibition account of RIF. Indeed, inhibition-related executive control may be a key mechanism subserving RIF (Román, Soriano, Gómez-Ariza, & Bajo, 2009; Levy & Anderson, 2002; Wu, Peters, Rittner, Cleland, & Smith, 2014). Individuals who demonstrate high levels of working memory capacity and executive control, for example, have also been shown to exhibit higher levels of RIF than individuals with reduced levels of working memory capacity and executive control (Aslan & Bäuml, 2011; Schilling, Storm, & Anderson, 2014; Storm & Bui, 2016). Moreover, recent work has observed reduced blood flow in the cortical regions associated with the non-practiced items during the RIF protocol (Wimber, Alink, Charest, Kriegeskorte, & Anderson, 2015). Inhibition may help resolve the competition that arises during item retrieval. In support of this inhibition-based mechanism, research demonstrates that, for non-practiced items, forgetting is more likely to occur for memorable (vs. non-memorable) objects, or for items that are presumed to cause interference or competition during retrieval practice (Anderson et al., 1994; Reppa, Williams, Worth, Greville, & Saunders, 2017; Storm, Bjork, & Bjork, 2007). Further, the prefrontal cortex plays a critical role in inhibitory-based executive control, and research demonstrates that when neural activity in the prefrontal cortex is blocked, RIF is attenuated (Stramaccia, Penolazzi, Altoe, & Galfano, 2017).

Various studies (Chang et al., 2015; Chang, Labban, Gapin, & Etnier, 2012; Etnier et al., 2016; Labban & Etnier, 2011, 2018; Loprinzi et al., 2019) have demonstrated that acute exercise can enhance episodic memory function, or the retrospective recall of information from a spatial-temporal context. As have been detailed thoroughly (El-Sayes, Harasym, Turco, Locke, & Nelson, 2019; Loprinzi, Edwards, & Frith, 2017), the mechanisms of this effect occur at multiple levels, including changes at the molecular and functional level. For example, acute exercise may upregulate levels of brain-derived neurotrophic factor (BDNF) and insulin-like growth factor-1 (IGF-1), which may help to facilitate long-term potentiation, or the functional connectivity across neurons. Although research on the effects of acute exercise on episodic memory function is accumulating, much less research has examined the effects of exercise on forgetting, let alone RIF (Ferguson, Cantrelle, & Loprinzi, 2018; Moore, Ryu, & Loprinzi, 2020). A recent study (Padilla, Andres, & Bajo, 2018) demonstrated that adults who were physically active, compared to their sedentary counterparts, exhibited greater RIF, presumably as a result of greater executive control and working memory associated with RIF. Notably, acute exercise has been shown to enhance aspects of cognitive inhibition (Hsieh, Huang, Wu, Chang, & Hung, 2018). For example, in a meta-analysis by Oberste et al. (2019), which evaluated 50 studies, acute exercise was effective in facilitating measures 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). Relatedly, in a review study (Rathore and Lom, 2017), acute exercise improved working memory performance in five of the seven evaluated studies. As stated, the prefrontal cortex may be a predominant structure involved in cognitive inhibition (Aron, 2007). The potential beneficial effects of acute exercise on cognitive inhibition may arise from exercise-induced increases in neural activity in the prefrontal cortex (Tsujii, Komatsu, and Sakatani, 2013). Other theoretical support for a relationship between exercise and RIF comes from shared affective mechanisms. Acute exercise, particularly moderate-intensity exercise, may induce a positive affective state (Ekkekakis, Parfitt, & Petruzzello, 2011), and some work has suggested that RIF is more likely to occur when individuals are in a relatively positive, as opposed to a negative or depressed, mood (Bäuml & Kuhbandner, 2007; Groome & Sterkaj, 2010; Storm & Jobe, 2012).

To our knowledge, only one study has evaluated the effects of acute exercise on RIF. In that experiment, Cantrelle and Loprinzi (2019) evaluated whether an acute bout of moderate-intensity exercise was associated (i.e., facilitated forgetting) with RIF. It was not. Specifically, they failed to observe a statistically significant difference in RIF between the exercise condition and the baseline control condition. The present experiment seeks to address the main limitation of that previous study, which was the relatively small sample size (n = 20 per group; N = 40), which likely limited statistical power to detect a statistically significant effect. Relatedly, that study failed to observe a statistically significant RIF effect, which may have been a result of the small sample size and/or the limited number of retrieval practice trials (i.e., two retrieval-practice sessions as opposed to the three or four sessions typically employed in the study of RIF). As such, the present experiment increased the number of retrieval-practice sessions to four and over tripled the sample size per group.

In addition to increasing the sample size and number of retrieval-practice sessions, the present experiment also evaluated whether there is an intensity-specific effect of acute exercise on RIF. An intensity-specific effect is plausible, as acute exercise intensity may, potentially, have a differential effect on memory function and executive control. Through a systematic review, Loprinzi (2018) demonstrated that acute moderate-intensity exercise may favor executive-control-related working memory, whereas acute high-intensity exercise may favor episodic memory function. However, other recent experimental work suggests that acute high-intensity exercise may be more beneficial for executive-control-related working memory (Tillman & Loprinzi, 2019) and source memory (Loprinzi, Rigdon, Javadi, & Kelemen, 2021). This also aligns with a recent meta-analysis (Oberste et al., 2019) showing that higher-intensity acute exercise may be more effective in enhancing cognitive inhibition when compared to lower-intensity acute exercise. These discrepant findings underscore the importance of additional work evaluating intensity-specific effects of acute exercise on memory and forgetting. Thus, a specific aim of this experiment was to evaluate the intensity-specific effects of acute exercise on RIF. It may be, for example, that the specific level of intensity employed in the previous study (Cantrelle & Loprinzi, 2019) was suboptimal for enhancing RIF. Thus, in the current experiment, we employed moderate-intensity and high-intensity exercise conditions that were relatively less and more intense than the condition employed previously, respectively.

Another notable novelty of this experiment is that we positioned the acute exercise not before the study phase, but rather, after the cued-recall test. Prior work suggests that acute exercise can help consolidate episodic memories (Loprinzi et al., 2019), and as such, we also implemented a second cued-recall test after the bout of exercise to evaluate whether exercise can help to preserve RIF over time.

The present experiment may have important implications. As discussed recently (Fawcett & Hulbert, 2020; Storm, 2011), forgetting may serve many purposes within our daily lives (e.g., updating long-term memory, overcoming mental fixation), and as such, identifying strategies like exercise that may facilitate this effect, is a worthwhile endeavor.

Chapter 3: Methods

3.1: Participants

The sample included 158 participants, including 54, 56, and 48, respectively, in the Control, Moderate-intensity, and Vigorous-intensity conditions. Based on a sensitivity analysis for a rmANOVA within-between interaction, with inputs of an α of 0.05, power of 0.80, 158 participants, 3 conditions, 8 measurements (Rp-, Nrp-, Rp+, Nrp+ for both Test 1 and Test 2) per condition, and an assumed repeated measures correlation of 0.50, we were powered to detect a small effect (i.e., effect size f of 0.09; small effect = 0.10 and medium effect = 0.25).

3.2: Study Design

A three-arm, parallel-group randomized controlled intervention was employed. Participants were randomized into one of three groups, including two experimental groups and a control group. The experimental groups engaged in a 20-min bout of treadmill exercise (either moderate-intensity or vigorous-intensity), while the control group engaged in a seated task. The exercise and control conditions occurred between a first cued-recall test and a second cued recall test that was identical to the first. The aim in adding the second cued recall test was to examine whether exercise might affect changes in RIF over time by influencing rates of reminiscence and oblivescence, such as by either helping participants recover Rp- items that had been previously forgotten, or by further solidifying the inhibition effect and preventing Rp- items from recovering.

3.3: Exercise Protocol

The acute bout of treadmill exercise lasted 20-minutes in duration, which aligns with previous work demonstrating an effect of acute exercise on episodic memory (Frith, Sng, & Loprinzi, 2017). Further, as demonstrated in a meta-analysis (Oberste et al., 2019), acute exercise lasting up to 20-minutes was most effective in enhancing inhibition when compared to other exercise durations. After the exercise bout, participants rested (sat and played Sudoku) for 5 minutes. After this resting period, they commenced the memory assessment. Notably, meta-analytic research demonstrates that there is no difference ($p > .41$) in inhibition when the cognitive task occurs within 15-minutes after the exercise bout or after a delay greater than 15-minutes (Oberste et al., 2019).

Participants randomized into the Moderate-intensity exercise group exercised at 50% of their heart rate reserve (HRR), whereas participants randomized into the Vigorous-intensity exercise group exercised at 80% of their HRR. These respective heart rate reserve thresholds represent moderate and vigorous-intensity exercise (Garber et al., 2011).

The HRR equation used to evaluate exercise intensity is: HRR = [(HRmax - HRrest) * % intensity] + HRrest. To calculate HRrest, at the beginning of the visit, participants sat quietly for 5 minutes, and HR was recorded from a chest-worn Polar HR monitor. To estimate HRmax, we calculated the participants estimated HRmax from the formula, 220-age.

3.4: Control Protocol

Similar to other studies (McNerney & Radvansky, 2015), participants randomized to the Control group completed a medium-level, online administered, Sudoku puzzle for 25 minutes (time-matched to the two experimental groups). The website for this puzzle is located here: https://www.websudoku.com/. Previous work demonstrates that playing Sudoku does not influence memory function, and as a result, may provide a suitable control condition (Blough et al., 2019).

3.5: Memory Assessment

After participants completed the study phase, retrieval practice, and first cued-recall test, they either exercised or engaged in a control task. Following this, they completed the second cued-recall test (which was identical to the first cued-recall test). Specific details of the memory task are as follows. In the study phase, participants were exposed to 72-word pairs, in which they were asked to memorize the paired words. In the retrieval practice phase, participants were cued to retrieve half of the word pairs. Lastly, in the final recall assessment, participants cue-recalled the 72 pairs that occurred during the study phase. In total, this task took about 10-minutes to complete.

Seventy-two category-exemplar pairs were used. The pairs consisted of six exemplars from 12 categories, with half of the exemplars from each category being high-frequency exemplars, and the other half being low-frequency exemplars.

Participants viewed these 72 pairs, one at a time, in a blocked-randomized order, for 3-seconds each. Afterward, participants were cued to retrieve the low-frequency exemplars from half of the categories. They had up to 10-seconds to complete their response to each of the category-plus-two-letter-stem retrieval cues. Participants were told that the answers would come from the earlier study phase. Four rounds of this retrieval practice occurred.

After the retrieval practice, participants engaged in the final recall task. This involved the recall of all 72 pairs that occurred during the study phase. Category-plus-one-letter-stem cues were presented in a block-randomized order for all 36 high-frequency exemplars, with 18 exemplars associated with the practiced categories (Rp-) and 18 exemplars associated with the non-practiced categories (Nrp-). The 36 low-frequency items, including 18 from practiced categories (Rp+) and 18 from non-practiced categories (Nrp+) were tested subsequently. Retrieval-induced forgetting (RIF) occurs if Rp- items are recalled less than Nrp- items. Retrieval practice (RP) occurs if Rp+ items are recalled more than Nrp+.

Chapter 4: Results

Table 1 displays the demographic and behavioral characteristics of the sample. Each group was similar regarding all participant characteristics.

Table 1. Participant characteristics.

Variable	**Control**	**Moderate-Intensity**	**Vigorous-Intensity**	**P-Value**
N	54	56	48	
Age, mean years	20.3 (3.2)	19.5 (2.1)	19.6 (1.5)	.17
Gender, % Women	59.3	51.8	52.0	.68
Race, % White	87.0	89.3	85.4	.62
BMI, mean kg/m^2	24.9 (3.6)	24.1 (4.1)	23.3 (3.7)	.11
MVPA, mean min/week	279.3 (247.2)	211.9 (173.0)	228.0 (179.6)	.20

BMI, Body mass index
MVPA, Moderate-to-vigorous physical activity
Values in parentheses are standard deviations
ANOVA was used to calculate p-values for continuous variables (e.g., age), whereas chi-square was used for categorical variables (e.g., gender)

Figure 1 displays the physiological response (heart rate) to the exercise and control conditions. In a 3 (group) x 6 (time period) RM-ANOVA, there was a significant main effect for time period, $F(3.09, 477.19) = 1652.5$, $p < .001$, $\eta^2 = .28$, main effect for group, $F(2, 154) = 785.9$, $p < .001$, $\eta^2 = .48$, and a time period by group interaction, $F(6.19, 477.19) = 477.87$, $p < .001$, $\eta^2 = .16$.

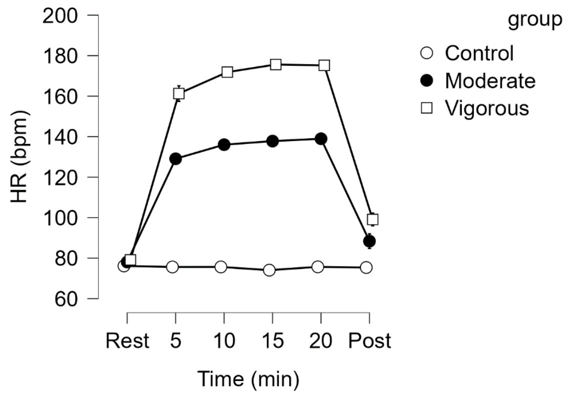

Figure 1. Heart rate (HR) responses to the exercise and control conditions for Experiment 3. Error bars (minimally visible) represent 95% CI.

The left side of Table 2 displays the recall performance of the low-frequency exemplars (i.e., the items employed to measure the benefits of retrieval practice on subsequent memory) at the immediate and delayed cued-recall tests across the exercise and control conditions. In a 3 (Group: Control, Moderate, Vigorous) × 2 (Item: Rp+ vs. Nrp+) × 2 (Test: First v Second) rmANOVA, a significant main effect of RP was observed, $F(1, 155) = 946.12$, $p < .001$, $\eta^2 = .56$, an Item by Test interaction was observed, $F(1, 155) = 12.19$, $p < .001$, $\eta^2 = .001$, but no other main or interaction effects were observed, *p*s > .27

The right side of Table 2 displays the immediate and delayed cued-recall performances of the high-frequency exemplars (i.e., the items employed to measure retrieval-induced forgetting) across the exercise and control conditions. In a 3 (Group: Control, Moderate, Vigorous) × 2 (Item: Rp- vs. Nrp-) × 2 (Test: First v Second) rmANOVA, there was a significant main effect for RIF, $F(1, 155) = 21.48$, $p < .001$, $\eta^2 = .03$, significant main effect for Test, $F(1, 155) = 50.667$, $p < .001$, $\eta^2 = .02$, significant Test by Group interaction, $F(2, 155) = 3.219$, $p = .04$, $\eta^2 = .002$, significant Test by

Group by RIF interaction, $F(2, 155) = 7.37$, $p < .001$, $\eta^2 = .004$. There was no RIF by Group interaction, $F(2, 155) = .195$, $p = .82$, $\eta^2 < .001$, no RIF by Test interaction, $F(1, 155) = .435$, $p = .51$, $\eta^2 < .001$, or main effect for Group, $F(2, 155) = 1.04$, $p = .35$, $\eta^2 = .008$.

Given the significant test by group by RIF interaction, a subsequent analysis was computed that collapsed the two exercise groups together. In a 2 (Group: Control, Exercise) × 2 (Item: Rp- vs. Nrp-) × 2 (Test: First v Second) rmANOVA, the Test by Group by RIF interaction remained, $F(1, 156) = 7.53$, $p = .007$, $\eta^2 = .002$. This three-way interaction was decomposed by employing contrasts tests to evaluate differences in Rp- and Nrp- across conditions and test. As shown in Figure 2, for the first assessment, Rp- was different than Nrp- for both the Control group, $M_{diff} = .065$, $t = 3.24$, $p = .002$, and the Exercise groups, $M_{diff} = .053$, $t = 3.18$, $p = .001$. However, for the second assessment, Rp- was not different than Nrp- for the Control group, $M_{diff} = .023$, $t = 1.18$, $p = .24$, but Rp- was different than Nrp- for the Exercise groups, $M_{diff} = .067$, $t = 4.18$, $p = .0001$.

Table 2. RP and RIF estimates across the experimental conditions and test.

	RP					RIF				
	Rp+	Nrp+	M_{diff}	95% CI	d	Rp-	Nrp-	M_{diff}	95% CI	d
First Test										
Control	.572 (.17)	.211 (.11)	.361	.320-.402	2.39	.367 (.13)	.432 (.14)	-.065	-.105, -.025	.44
Moderate	.578 (.14)	.238 (.14)	.340	.304-.375	2.55	.394 (.14)	.432 (.12)	-.038	-.085, .007	.22
Vigorous	.591 (.15)	.227 (.11)	.364	.317-.410	2.28	.409 (.15)	.478 (.14)	-.069	-.117, -.021	.42
Second Test										
Control	.569 (.17)	.237 (.14)	.332	.296-.368	2.53	.447 (.14)	.470 (.16)	-.023	-.062, .016	.16
Moderate	.554 (.15)	.251 (.15)	.303	.262-.343	2.00	.402 (.15)	.483 (.13)	-.081	-.123, -.039	.52
Vigorous	.580 (.16)	.242 (.13)	.338	.289-.387	2.01	.448 (.18)	.498 (.13)	-.049	-.099, -.0004	.29

Values in parentheses are standard deviations. 95% CI represents the 95% confidence interval of the M_{diff} (mean difference). Cohens d calculated as mean difference / sd difference.

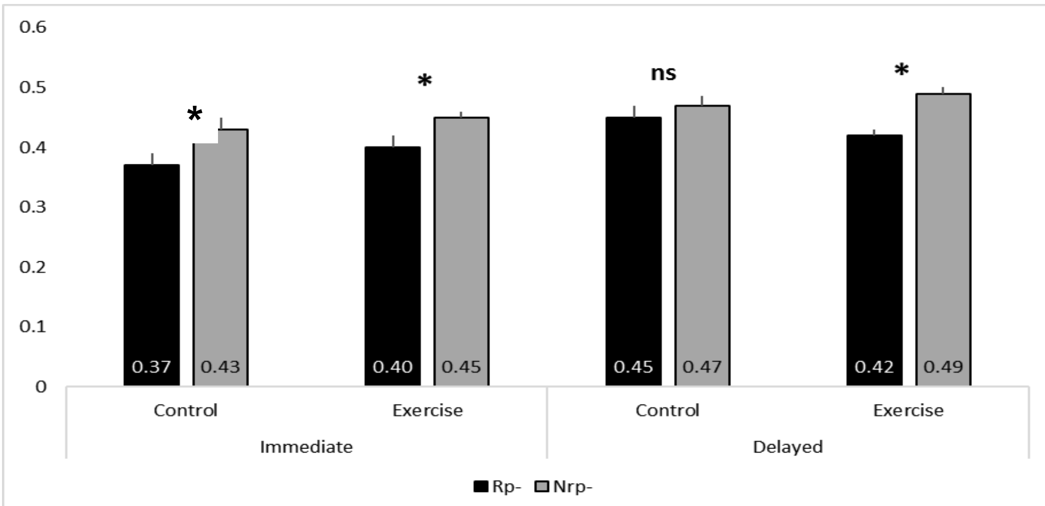

Figure 1. Retrieval-induced forgetting results as a function of condition and time. Error bars represent standard errors. * = statistically significant ($p < .05$); ns = not statistically significant.

Chapter 5 - Discussion

Prior work suggests that remembering a set of information can induce forgetting of related information (i.e., RIF) due to inhibition of the related, unpracticed information. Research also demonstrates that acute exercise can facilitate cognitive inhibition, ultimately suggesting that acute exercise may augment a RIF effect. The present experiment demonstrated two notable findings: (1) RIF was reliably induced when implementing a cued-recall task and (2) acute exercise, regardless of intensity, preserved RIF when occurring between the cued-recall assessments. These findings are discussed in the following narrative.

5.1: Acute Exercise Prior to Study on RIF

If RIF is the result of an inhibitory process that takes place during retrieval practice, then by enhancing cognition-related inhibition, acute exercise may enhance the forgetting of the non-practiced items. Given the role of acute exercise on post-exercise cognitive inhibition (Oberste et al., 2019), we anticipated that acute exercise, prior to the study of items, would prime inhibition mechanisms to augment RIF.

The findings of this experiment relating to the null exercise effects, align with the results of a previous preliminary experiment on this topic (Cantrelle & Loprinzi, 2019) and are compelling for multiple reasons. First, with approximately four times as many subjects than in the previous study (Cantrelle & Loprinzi, 2019), the lack of a significant effect seems unlikely to be the result of inadequate power. Second, the null effect has now been observed across three different levels of exercise intensity, suggesting that the failure to observe an effect is unlikely due to not selecting the appropriate level of exercise intensity. Our findings, along with those of Cantrelle and Loprinzi, taken together, tentatively suggest that exercise may not influence post-exercise executive control mechanisms in a way that has a meaningful impact on the way retrieval impacts memory. At the very least, we found no evidence that exercise either affects the extent to which practiced items benefit from retrieval, or the extent to which non-practiced items are impaired by retrieval.

5.2: Acute Exercise after Recall Preserves RIF

Another key finding of the current study demonstrates that acute exercise between two cued-recall assessments may help to preserve RIF over time. Based on the current results, there appears to be a natural tendency to recover Rp- items (relative to Nrp items) following an initial test. Exercise may disrupt this recovery by making it less likely for Rp- items that were forgotten to become recallable on the second test, while also making it more likely for Rp- items that were recalled on the first test to remain recallable on the second test. Items have some potential probability of being recalled at a given time, and depending on various factors, can become more/less recallable at a future time (Estes, 1955). It is possible that Rp- items are in a fragile state following retrieval practice, one that makes them vulnerable to further disruption, such as that caused by an exercise-induced change in context. Another possibility is that exercise might solidify (or at least make more persistent) the changes in memory that occur as a consequence of retrieval practice. Although not assessed between tests, prior work shows that, when acute exercise occurs before encoding items in a multi-trial list-learning task, exercise may help to increase the proportion of item gains across trials (Sng, Frith, & Loprinzi, 2018). Collectively, these results suggest that exercise may help to improve memory, either by increasing or decreasing the accessibility of items in memory.

5.3: Conclusion

In conclusion, acute exercise prior to study does not seem to influence RIF. However, acute exercise after recall may preserve the RIF effect. Future work may wish to experimentally evaluate candidate mechanisms of this RIF preservation effect. Nevertheless, these findings could be beneficial for those looking to increase memory performance in various aspects of life. For example, if an individual is studying for an exam, and they wish to improve their ability to recall a key part of information that may be clouded by a host of other related memories, a short bout of exercise after learning may be beneficial for them.

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