Exercise and Retrieval-Induced Forgetting

Justin Cantrelle and Paul Loprinzi *

Exercise & Memory Laboratory, Department of Health, Exercise Science and Recreation Management,
The University of Mississippi, University, MS 38677, USA
* Correspondence: pdloprin@olemiss.edu

Abstract: Retrieving a subset of items from memory can cause forgetting of other related items in memory, referred to as retrieval-induced forgetting (RIF). This type of forgetting (RIF) is thought to be related to working memory and executive control processes, of which are known to be influenced by acute exercise. The objective of this study was to evaluate whether acute exercise could accentuate RIF. A two-arm, parallel-group randomized controlled intervention was employed. Participants (N = 40) were randomized into one of two groups, including an experimental group (15-min of moderate-intensity exercise) and a control group (time-matched seated task). Retrieval-induced forgetting (RIF) and retrieval practice (RP) were assessed from a category-exemplar memory task. There was no significant main effect for RIF and no group by RIF interaction, suggesting that acute exercise did not alter RIF more than the control group. There was a significant main effect for RP, but there was no group by RP interaction. These RP findings align with the RIF findings, indicating that acute exercise did not alter RP more so than the control group. In conclusion, our experimental results do not provide support for an association of acute exercise on retrieval-induced forgetting or retrieval practice.

Keywords: executive control; memory interference; physical activity; working memory

1. Introduction

Among young adults, emerging experimental work has started to examine the effects of exercise on memory function. This accumulating body of work provides suggestive evidence that acute exercise may enhance memory function [1–4]. We have previously detailed the dearth of research on this topic among this population [5]. The mechanisms through which exercise may influence memory function has also been extensively detailed by our group [6–10]. Such effects may include, for example, exercise-induced alterations in neuronal excitability, growth factor production, and modulation of key hormones (e.g., IGF-1).

Research demonstrates that retrieving a subset of items from memory can cause forgetting of other related items in memory [11]. This phenomenon is referred to as retrieval-induced forgetting (RIF). No research, however, has evaluated whether acute exercise can influence RIF. As recommended elsewhere [5], the purpose of this study was to evaluate whether acute exercise was associated with RIF, written herein as a brief report. We specifically positioned the exercise stimulus to occur shortly before the memory task, as emerging work demonstrates that this is the optimal time to exercise [3,12,13].

We hypothesized that acute exercise would accentuate RIF. This stems from emerging work showing that RIF is enhanced among individuals with superior working memory capacity, and thus, among those who exhibit greater inhibitory processes mediated by executive control [11]. It is conceivable that acute exercise may enhance RIF as research demonstrates that acute exercise is favorably associated with inhibitory and executive control processes [14–16]. Further, emerging work demonstrates that acute exercise may more favorably influence prefrontal cortex-dependent cognition

as compared to hippocampal-dependent cognition [17]. In addition to this being a novel paradigm, this work has important implications, as forgetting may be viewed as an adaptive memory outcome to help prevent memory interference [18].

2. Methods

2.1. Study Design

A two-arm, parallel-group randomized controlled intervention was employed. Participants were randomized into one of two groups, including an experimental group and a control group. The experimental group walked briskly for 15 min, while the control group engaged in a seated task. This study was approved by the ethics committee at the University of Mississippi (#18–119) and participants provided written voluntary consent prior to participation.

2.2. Participants

Each group included 20 participants (N = 40). Participants, on average, were 20 years, with the sample being predominately female (60.0% and 75.0% in the exercise and control groups, respectively). This was based from a power analysis indicating sample sizes ranging from 8–24 (d, 0.84–1.36; two-tailed α error probability, 0.05; 1-β error probability, 0.80; allocation ratio, 1) [11,19]. Recruitment occurred via a convenience-based, non-probability sampling approach (classroom announcement and word-of-mouth). Participants included undergraduate and graduate students between the ages of 18 and 35 years.

Similar to other studies [20,21], participants were excluded if they:

1. Self-reported as a daily smoker [22,23]
2. Self-reported being pregnant [24]
3. Exercised within 5 hours of testing [25]
4. Consumed caffeine within 3 hours of testing [26]
5. Had a concussion or head trauma within the past 30 days [27]
6. Took marijuana or other illegal drugs within the past 30 days [28]
7. Were considered a regular alcohol user (>30 drinks/month for women; >60 drinks/month for men) [29]

2.3. Exercise Protocol

The exercise bout involved exercising on a treadmill for 15 min. This specific exercise duration (15 min) was chosen as our previous work demonstrates a memory-enhancement effect from this duration [3,12,30–32]. Participants walked at approximately 70% of their estimated heart rate max (220-age), which corresponded with moderate-intensity exercise [33].

Immediately after the bout of exercise, participants rested in a seated position for 5 min. During this resting period, they played an on-line game of Sudoku (described below) to prevent boredom. After this resting period, they commenced the memory assessment, as described below.

2.4. Control Protocol

Similar to other studies [34], those randomized to the active control group completed a medium-level, on-line administered, Sudoku puzzle for 20 min. The website for this puzzle is located here: https://www.websudoku.com/. This control task has been shown to not prime or enhance memory function [35].

2.5. Memory Assessment

Memory function was assessed from three sequential phases, including a study phase, retrieval practice, and a final memory recall assessment. 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. Details are described as follows.

Seventy-two category-exemplar pairs from previous research was used [11]. 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 s each. Afterward, participants were cued to retrieve the low-frequency exemplars from half of the categories. They had up to 10 s 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. Two 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+.

2.6. Additional Measurements

As a measure of habitual physical activity behavior, participants completed the Physical Activity Vital Signs Questionnaire, which reported time spent per week in moderate-to-vigorous physical activity (MVPA) [36]. Height/weight (BMI) was measured to provide anthropometric characteristics of the sample. Furthermore, before, during and after the exercise and control conditions, heart rate (chest-strapped Polar monitor, F1 model) was assessed.

2.7. Statistical Analysis

All statistical analyses were computed in Jasp (v. 0.9.2). For RIF, a 2 (Rp- and Nrp-) x 2 (exercise and control) ANOVA was employed. For RIP, a 2 (Rp+ and Nrp+) x 2 (exercise and control) ANOVA was employed. For the heart rate data, we employed a 4 (resting, midpoint, endpoint, post-exercise) x 2 (exercise and control) RM-ANOVA. Statistical significance was set at an alpha of 0.05.

3. Results

Table 1 displays the characteristics of the sample. Table 2 displays the physiological (heart rate) responses to the exercise and control protocols. There were no changes in heart rate over the control period, however, for the exercise group, heart rate increased from 73 bpm (rest) to 129.1 bpm ($p < 0.001$). As expected, there was a statistically significant main effect for heart rate, $F(3, 114) = 196.7$, $p < 0.001$, $\eta^2_p = 0.84$, main effect for group, $F(1, 38) = 45.6$, $p < 0.001$, $\eta^2_p = 0.54$, and heart rate by group interaction, $F(3, 114) = 192.8$, $p < 0.001$, $\eta^2_p = 0.84$. Bonferroni-corrected post-hoc tests indicated that resting heart rate was significantly different from the heart rate at midpoint ($p < 0.001$) and endpoint ($p < 0.001$), but not post-exercise ($p = 0.15$). Midpoint heart was not different to endpoint heart rate ($p = 0.99$) but was different to post-exercise heart rate ($p < 0.001$).

For RIF (Figure 1), we observed no main effect for RIF, $F(1, 38) = 2.43$, $p = 0.12$, $\eta^2_p = 0.06$, no main effect for group, $F(1, 38) = 0.08$, $p = 0.77$, $\eta^2_p = 0.002$, and no RIF by group interaction, $F(1, 38) = 0.26$, $p = 0.61$, $\eta^2_p = 0.007$. For RP (Figure 2), we observed no main effect for group, $F(1, 38) = 0.08$, $p = 0.77$, $\eta^2_p = 0.002$, and no RP by group interaction, $F(1, 38) = 0.40$, $p = 0.53$, $\eta^2_p = 0.01$. However, we did observe a main effect for RP, $F(1, 38) = 166.6$, $p < 0.001$, $\eta^2_p = 0.81$. The Bonferroni-corrected post-hoc test indicated a significant difference between Rp+ and Nrp+ ($p < 0.001$).

Table 1. Sample characteristics.

Variable	Exercise (n = 20)	Control (n = 20)
Age, mean years	20.45 (0.68)	20.80 (1.1)
Gender, % female	60.0	75.0
Race, % white	70.0	80.0
Body mass index, mean kg/m^2	25.29 (4.31)	23.84 (3.1)
MVPA, mean min/week	227.2 (203.0)	206.2 (197.0)

Table 2. Physiological responses to the exercise and control protocols.

Variable	Exercise (n = 20)	Control (n = 20)
Heart rate, mean bpm		
Rest	73.8 (13.7)	80.3 (14.1)
Midpoint	127.2 (8.4)	81.0 (13.4)
Endpoint	129.1 (9.2)	79.4 (12.5)
Post	83.0 (13.8)	79.3 (11.6)
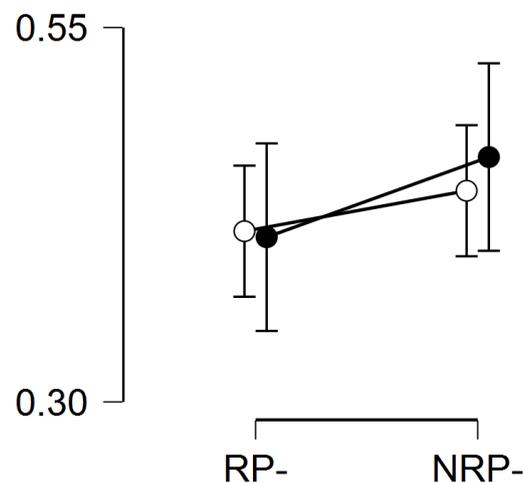
Figure 1. Retrieval-induced forgetting (RIF) scores across the experimental conditions. RIF occurs if Rp- items were recalled less than Nrp- items.
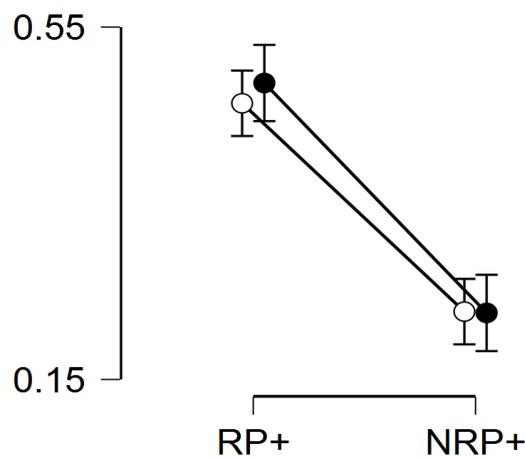
Figure 2. Retrieval practice (RP) scores across the experimental conditions. RP occurs if Rp+ items were recalled more than Nrp+.

4. Discussion

Individuals with greater working memory capacity and executive control processes have greater retrieval-induced forgetting (RIF). Similarly, those with impaired executive control have less RIF [37]. Based on this, coupled with evidence that exercise may enhance executive control [14–16], we explored whether acute exercise could facilitate RIF. Although our RIF findings were not statistically significant (e.g., Rp-, 0.41; Nrp-, 0.46), which was likely to be a result of our relatively small sample, they were within the same ballpark as other studies (e.g., Rp-, 0.41; Nrp-, 0.48) [11]. Future work, for example, should consider increasing the number of times the material is presented in the retrieval practice session, which may help to facilitate a RIF effect. Similarly, our statistically significant RP results (Rp+, 0.48; Nrp+, 0.22) aligned with other experiments (e.g., Rp+, 0.59; Nrp+, 0.33) [11]. However, of interest to this experiment was that we did not observe a differential RIF and RP between the exercise and control conditions.

Potential explanations for our non-differential findings across the exercise and control groups are as follows; given our relatively small sample size, it is possible that we had reduced statistical power to observe significant differences between the groups. As such, future work on this topic should employ a larger sample size. With between-subject designs, often the greatest source of variance comes from individual differences [31,38]. Thus, future experimental work on this topic should consider re-evaluating this paradigm while employing a within-subject design. That is, in this type of within-subject design, a baseline (control) assessment of RIF can be determined, which will allow for a better evaluation of the potential extent to which acute exercise may influence RIF. Furthermore, perhaps our imposed exercise intensity was too low to observe enhancements of executive control processes that are thought to mediate RIF. However, recent work suggests that a high exercise intensity can impair, not enhance, working memory and executive control processes [39]. Future work would benefit by evaluating multiple intensities of exercise on RIF and also concurrently measure executive control processes. It would also be of interest to evaluate open (e.g., badminton) versus closed (walking) skilled exercises on RIF, as recent work suggests that the type of exercise (open vs. closed) may have a unique effect on markers of synaptic plasticity as well as on behavioral measures of executive control [15]. Additionally, recent work suggests that chronic exercise, when compared to acute exercise, may have a greater effect on executive control [40]. Consequently, it would be useful for future work on this paradigm to examine the effects of acute and chronic exercise on RIF.

In conclusion, this novel experiment evaluated whether acute moderate-intensity exercise was associated with RIF. We did not observe evidence of a statistically significant association between moderate-intensity acute exercise on RIF. Future work evaluating this novel paradigm is warranted. Such work should consider increasing the sample size, employing a within-subject design, and evaluating multiple exercise intensities.

Author Contributions: Author J.C. collected the data and provided feedback on the manuscript. Author P.L. conceptualized the study, computed the analyses, and prepared the initial draft of the manuscript.

References

1. Loprinzi, P.D.; Kane, C.J. Exercise and cognitive function: A randomized controlled trial examining acute exercise and free-living physical activity and sedentary effects. *Mayo Clin. Proc.* **2015**, *90*, 450–460. [CrossRef] [PubMed]

2. Crush, E.A.; Loprinzi, P.D. Dose-Response Effects of Exercise Duration and Recovery on Cognitive Functioning. *Percept. Mot. Ski.* **2017**, *124*, 1164–1193. [CrossRef]

3. Frith, E.; Sng, E.; Loprinzi, P.D. 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.* **2017**, *46*, 2557–2564. [CrossRef] [PubMed]

4. Sng, E.; Frith, E.; Loprinzi, P.D. Temporal effects of acute walking exercise on learning and memory. *Am. J. Health Promot.* **2017**, *32*, 1518–1525. [CrossRef] [PubMed]

5. Loprinzi, P.D.; Frith, E.; Edwards, M.K.; Sng, E.; Ashpole, N. The effects of exercise on memory function among young-to middle-age adults: Systematic review and recommendations for future research. *Am. J. Health Promot.* **2017**, *32*, 691–704. [CrossRef]

6. Loprinzi, P.D.; Edwards, M.K.; Frith, E. Potential avenues for exercise to activate episodic memory-related pathways: A narrative review. *Eur. J. Neurosci.* **2017**, *46*, 2067–2077. [CrossRef]

7. Loprinzi, P.D.; Ponce, P.; Frith, E. Hypothesized mechanisms through which acute exercise influences episodic memory. *Physiol. Int.* **2018**, *105*, 285–297. [CrossRef]

8. Loprinzi, P.D. IGF-1 in exercise-induced enhancement of episodic memory. *Acta Physiol.* **2018**, *226*, e13154. [CrossRef]

9. Loprinzi, P.D.; Frith, E. A brief primer on the mediational role of BDNF in the exercise-memory link. *Clin. Physiol. Funct. Imaging* **2018**, *39*, 9–14. [CrossRef]

10. Frith, E.; Loprinzi, P.D. Physical activity and individual cognitive funcion parameters: Unique exercise-induced mechansims. *J. Cogn. Behav. Psychother. Res.* **2018**, *7*, 92–106. [CrossRef]

11. Storm, B.C.; Bui, D.C. Retrieval-practice task affects relationship between working memory capacity and retrieval-induced forgetting. *Memory* **2016**, *24*, 1407–1418. [CrossRef] [PubMed]

12. Sng, E.; Frith, E.; Loprinzi, P.D. Experimental effects of acute exercise on episodic memory acquisition: Decomposition of multi-trial gains and losses. *Physiol. Behav.* **2018**, *186*, 82–84. [CrossRef] [PubMed]

13. Loprinzi, P.D.; Blough, J.; Crawford, L.; Ryu, S.; Zou, L.; Li, H. The temporal effects of acute exercise on episodic memory function: Systematic review with meta-analysis. *Brain Sci.* **2019**, *9*, 87. [CrossRef] [PubMed]

14. Hsieh, S.S.; Huang, C.J.; Wu, C.T.; Chang, Y.K.; Hung, T.M. Acute Exercise Facilitates the N450 Inhibition Marker and P3 Attention Marker during Stroop Test in Young and Older Adults. *J. Clin. Med.* **2018**, *7*, 391. [CrossRef] [PubMed]

15. Hung, C.L.; Tseng, J.W.; Chao, H.H.; Hung, T.M.; Wang, H.S. Effect of Acute Exercise Mode on Serum Brain-Derived Neurotrophic Factor (BDNF) and Task Switching Performance. *J. Clin. Med.* **2018**, *7*, 301. [CrossRef] [PubMed]

16. Chen, F.T.; Etnier, J.L.; Wu, C.H.; Cho, Y.M.; Hung, T.M.; Chang, Y.K. Dose-Response Relationship between Exercise Duration and Executive Function in Older Adults. *J. Clin. Med.* **2018**, *7*, 279. [CrossRef] [PubMed]

17. Basso, J.C.; Shang, A.; Elman, M.; Karmouta, R.; Suzuki, W.A. Acute Exercise Improves Prefrontal Cortex but not Hippocampal Function in Healthy Adults. *J. Int. Neuropsychol. Soc.* **2015**, *21*, 791–801. [CrossRef] [PubMed]

18. Loprinzi, P.D. An integrated model of acute exercise on memory function. *Med. Hypotheses* **2019**, *126*, 51–59. [CrossRef]

19. Verde, M.F.; Perfect, T.J. Retrieval-induced forgetting in recognition is absent under time pressure. *Psychon. Bull. Rev.* **2011**, *18*, 1166–1171. [CrossRef]

20. Yanes, D.; Loprinzi, P.D. Experimental Effects of Acute Exercise on Iconic Memory, Short-Term Episodic, and Long-Term Episodic Memory. *J. Clin. Med.* **2018**, *7*, 146. [CrossRef]

21. Siddiqui, A.; Loprinzi, P.D. Experimental Investigation of the Time Course Effects of Acute Exercise on False Episodic Memory. *J. Clin. Med.* **2018**, *7*, 157. [CrossRef] [PubMed]

22. Jubelt, L.E.; Barr, R.S.; Goff, D.C.; Logvinenko, T.; Weiss, A.P.; Evins, A.E. Effects of transdermal nicotine on episodic memory in non-smokers with and without schizophrenia. *Psychopharmacology* **2008**, *199*, 89–98. [CrossRef] [PubMed]

23. Klaming, R.; Annese, J.; Veltman, D.J.; Comijs, H.C. 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.* **2016**, *24*, 528–542. [CrossRef] [PubMed]

24. Henry, J.D.; Rendell, P.G. A review of the impact of pregnancy on memory function. *J. Clin. Exp. Neuropsychol.* **2007**, *29*, 793–803. [CrossRef] [PubMed]

25. Labban, J.D.; Etnier, J.L. Effects of acute exercise on long-term memory. *Res. Q. Exerc. Sport* **2011**, *82*, 712–721. [CrossRef] [PubMed]

26. Sherman, S.M.; Buckley, T.P.; Baena, E.; Ryan, L. Caffeine Enhances Memory Performance in Young Adults during Their Non-optimal Time of Day. *Front. Psychol.* **2016**, *7*, 1764. [CrossRef]

27. Wammes, J.D.; Good, T.J.; Fernandes, M.A. Autobiographical and episodic memory deficits in mild traumatic brain injury. *Brain Cogn.* **2017**, *111*, 112–126. [CrossRef]

28. Hindocha, C.; Freeman, T.P.; Xia, J.X.; Shaban, N.D.C.; Curran, H.V. Acute memory and psychotomimetic effects of cannabis and tobacco both 'joint' and individually: A placebo-controlled trial. *Psychol. Med.* **2017**, *47*, 2708–2719. [CrossRef]

29. Le Berre, A.P.; Fama, R.; Sullivan, E.V. Executive Functions, Memory, and Social Cognitive Deficits and Recovery in Chronic Alcoholism: A Critical Review to Inform Future Research. *Alcohol. Clin. Exp. Res.* **2017**, *41*, 1432–1443. [CrossRef]

30. Dilley, E.K.; Zou, L.; Loprinzi, P.D. The effects of acute exercise intensity on episodic memory and false memory among young adult college students. *Health Promot. Perspect.* **2019**, *9*, 143–149. [CrossRef]

31. Haynes Iv, J.T.; Frith, E.; Sng, E.; Loprinzi, P.D. Experimental Effects of Acute Exercise on Episodic Memory Function: Considerations for the Timing of Exercise. *Psychol. Rep.* **2018**. [CrossRef] [PubMed]

32. Green, D.; Loprinzi, P.D. Experimental Effects of Acute Exercise on Prospective Memory and False Memory. *Psychol. Rep.* **2018**. [CrossRef] [PubMed]

33. Garber, C.E.; Blissmer, B.; Deschenes, M.R.; Franklin, B.A.; Lamonte, M.J.; Lee, I.M. American College of Sports Medicine position stand. Quantity and quality of exercise for developing and maintaining cardiorespiratory, musculoskeletal, and neuromotor fitness in apparently healthy adults: Guidance for prescribing exercise. *Med. Sci. Sports Exerc.* **2011**, *43*, 1334–1359. [CrossRef] [PubMed]

34. McNerney, M.W.; Radvansky, G.A. Mind racing: The influence of exercise on long-term memory consolidation. *Memory* **2015**, *23*, 1140–1151. [CrossRef] [PubMed]

35. Blough, J.; Loprinzi, P.D. Experimental manipulation of psychological control scenarios: Implications for exercise and memory research. *Psych* **2019**, *1*, 279–289. [CrossRef]

36. Ball, T.J.; Joy, E.A.; Gren, L.H.; Shaw, J.M. Concurrent Validity of a Self-Reported Physical Activity "Vital Sign" Questionnaire With Adult Primary Care Patients. *Prev. Chronic Dis.* **2016**, *13*, E16. [CrossRef] [PubMed]

37. Roman, P.; Soriano, M.F.; Gomez-Ariza, C.J.; Bajo, M.T. Retrieval-induced forgetting and executive control. *Psychol. Sci.* **2009**, *20*, 1053–1058. [CrossRef]

38. Thompson, V.A.; Campbell, J.I. A power struggle: Between- vs. within-subjects designs in deductive reasoning research. *Psychologia* **2004**, *47*, 277–296. [CrossRef]

39. Loprinzi, P.D. Intensity-specific effects of acute exercise on human memory function: Considerations for the timing of exercise and the type of memory. *Health Promot. Perspect.* **2018**, *8*, 255. [CrossRef]

40. Rathore, A.; Lom, B. 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. *Syst. Rev.* **2017**, *6*, 124. [CrossRef]