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The Effects of Acute Exercise on Retroactive Memory Interference

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Abstract

Purpose: Retroactive interference involves the disruption of previously encoded information from newly learned information and thus may impair the consolidation of long-term memory. The objective of this study was to evaluate whether acute exercise can attenuate retroactive memory interference.

Design: Three experimental studies were employed. Experiment 1 employed a between-subject randomized control trial (RCT) involving moderate-intensity walking (15 minutes). Experiment 2 employed a between-subject RCT involving high-intensity jogging (15 minutes). Experiment 3 employed a within-subject RCT involving moderate-intensity walking (15 minutes).

Setting: University setting.

Participants: One hundred twelve young adults.

Measures: After exercise, memory interference was evaluated from an episodic word-list memory task, involving the recall of 2 word lists.

Results: The pooled effect size (standard difference in means: −0.35; 95% confidence interval: −0.64 to −0.06) across the 3 experiments was statistically significant ($P = .01$).

Conclusion: We provide suggestive evidence that acute, short-duration exercise may help attenuate a retroactive memory interference effect. Implications of these findings for exercise to improve memory and attenuate memory decay are discussed.

Keywords

cognition, encoding, hippocampus, inhibition, learning, memory, physical activity, prefrontal cortex

Purpose

Interfering stimuli can disrupt the consolidation process of memories and in turn induce forgetting.[1] Broadly classified, proactive interference includes previously encoded information interfering with subsequent information, whereas retroactive interference involves the disruption of previously encoded information from newly learned information. Notably, however, memory interference, based on the context, may be viewed in a positive light, as interfering stimuli can help to reduce negative emotional memories.[2]

The present article is focused on retroactive interference (as opposed to proactive interference). From a clinical perspective, which often involves multiple cognitive assessments, the implementation of a series of cognitive evaluations can induce a retroactive interference effect and in turn confound cognitively based clinical outcomes.[3] The evaluation of retroactive interference can occur from multiple assessment types but often includes, for example, the presentation of a list of words (list A), followed by a second word list (list B), and then the recall of the first list (list A). In this situation, retroactive interference may occur from list B interfering with the recall of list A. Various factors may contribute to a word list–based retroactive interference effect, including the length of the words[4] and the temporal period (eg, the delay period in which list B is presented after list A) of the retroactive interference.[5,6] Notably, when the interfering stimuli (eg, list B) occurs within close proximity to the initial stimuli (eg, list A), retroactive interference is more likely to occur,[7] but this may depend on the population and memory type evaluated.[8] Especially in adults, if the retroactive interference task (eg, list B) is semantically similar to the initial memory task (eg, list A), retroactive interference is more likely to occur.[9-11] However, mere cognitive engagement of a distractor task may not induce retroactive interference, as distractor tasks that

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involve hippocampal processing are more likely to induce retroactive interference.[12]

Several factors have been identified as potential strategies to minimize a retroactive interference effect. Memory reactivation of the initial learning task, which is defined as the restoration of mental representations formed during primary encoding of an event,[13] as well as mental practice,[14] has been effective in attenuating retroactive interference. Neurogenesis, which is robustly influenced by exercise,[15] has also been shown to induce resistance to retroactive interference.[16] Further, the medial prefrontal cortex and the hippocampus, both of which are activated by exercise,[17,18] play an important role in attenuating retroactive interference.[19-21]

Although accumulating research demonstrates that exercise may enhance memory function,[22] very little research has evaluated whether exercise can attenuate a memory interference effect. Further exploration of the potential for an exercise-induced attenuation of retroactive interference is warranted, particularly within the health promotion discipline. Impoverished memory for old information is signified by retroactive interference, as recently presented information masks one's ability to recall previously learned concepts.[1] Aside from the potential mental health benefits of inaccessible negative, traumatic memories,[2] retroactive interference may also impede the unique human ability to construct rich schemas of knowledge and manipulate knowledge representation in service of knowledge acquisition and problem-solving across the life span. To this end, we contend that exploring the effects of retroactive interference is an important public health topic applicable to domains as diverse as education and pedagogy, mental health,[2] and broader comprehension of human cognition and behavior. To our knowledge, only 3 studies have evaluated whether exercise can minimize a memory interference effect.[23-25] These studies have come from our laboratory. We provided suggestive evidence that acute exercise can attenuate a proactive interference effect.[23,24] Less research, however, has examined the effects of acute exercise on retroactive interference,[25] of which, also provided some evidence of a potential attenuation effect from acute exercise. The present study extends this emerging line of inquiry by further evaluating the potential effects of acute exercise on attenuating retroactive interference. Herein, we provide data from 3 experimental studies that include varying exercise intensities, as exercise intensity may modulate memory function.[26] We hypothesize that acute exercise, across both moderate and high intensity, will attenuate retroactive interference.

Methods

Design

Three experimental studies were employed. All experiments were approved by the authors' institutional review board, and participant consent was provided prior to data collection. Experiment 1 employed a between-subject randomized controlled trial involving moderate-intensity walking; participants were randomized into a walking or control group. Experiment 2 employed a between-subject randomized controlled trial involving high-intensity jogging; participants were randomized into a jogging or control group. Lastly, experiment 3 employed a within-subject randomized controlled trial involving moderate-intensity walking; participants completed counterbalanced visits (at least 24 hours between visits, with the visits occurring at approximately the same time of day) of either walking or sitting.

The present study utilizes secondary data from previously published experiments in our laboratory. The primary results from experiment 1,[27] including an assessment of proactive interference,[23] are discussed elsewhere. Similarly, the primary results,[28] along with proactive interference results,[23] for experiment 2, can be found elsewhere. Lastly, the primary results,[29] along with the proactive interference results,[24] for experiment 3, are discussed elsewhere. Notably, for these 3 experiments, there were 4 experimental arms, including exercise prior to the memory task, exercise during the memory task, exercise after the memory task, and a seated control group. For the present article, only the exercise prior group and the control group were included, as the purpose of the present article was to evaluate whether exercise prior to an initial memory stimulus may attenuate a retroactive memory interference effect.

Sample

The sample included 44 participants for experiment 1 ($n = 22$ per group), 44 for experiment 2 ($n = 22$ per group), and 24 for experiment 3. This is based from a power analysis, indicating a sample size of 20 would be needed for sufficient power (d: 0.90; 2-tailed α error probability: .05; 1-β error probability: .80). This was informed from related work evaluating the effects of acute aerobic exercise on episodic memory outcomes, which demonstrated relatively large effect sizes (d: 1.04; $\eta_p^2 = 0.23$-0.29).[30,31] Participants were recruited via a nonrandom, convenience-based sampling approach (e-mail correspondence and word-of-mouth) at the authors' university. Undergraduate and graduate students were recruited. Additionally, and identical to other studies,[32] participants were excluded if they:

- Self-reported as a daily smoker.[33,34]
- Self-reported being pregnant.[35]
- Exercised within 5 hours of testing.[30]
- Consumed caffeine within 3 hours of testing.[36]
- Had a concussion or head trauma within the past 30 days.[37]
- Took marijuana or other illegal drugs within the past 30 days.[38]
- Were considered a daily alcohol user (>30 drinks/month for women; >60 drinks/month for men).[39]

Measures

Exercise Protocol

Experiment 1 (walking, between-subject design). Participants walked on a treadmill for 15 minutes at a self-selected pace.

Heart rate was monitored at baseline and at the end of the protocol. The specific instructions were: "Please select a pace similar to one you would choose if you were late to class. Thus, it will not be a leisurely walk. Nor will it be a run." This self-selected intensity protocol was employed to maximize generalizability. After the walk, they rested (sat) for 5 minutes before completing the memory task.

Experiment 2 (jogging, between-subject design). Participants jogged on a treadmill for 15 minutes with the first 5 minutes at an easy self-selected jogging intensity, maintaining a pace corresponding to an 11 to 12 rating of perceived exertion (RPE; range: 6-20).[40] The next 5 minutes were completed at a self-selected faster pace (keeping the pace at an RPE of 13-15) and the last 5 minutes at a self-selected hard pace (keeping the pace at an RPE of 16-20). This progressive exercise intensity was employed to ensure that all participants reached a high intensity by the end of the exercise bout. Heart rate was monitored at baseline and at the end of the protocol. After the jog, they rested (sat) for 5 minutes before completing the memory task.

Experiment 3 (walking, within-subject design). The same protocol for experiment 1 was implemented for experiment 3. That is, participants walked on a treadmill for 15 minutes at a self-selected pace. Heart rate was monitored at baseline and at the end of the protocol. The specific instructions were "Please select a pace similar to one you would choose if you were late to class. Thus, it will not be a leisurely walk. Nor will it be a run." After the walk, they rested (sat) for 5 minutes before completing the memory task.

Control Protocol

For all 3 experiments, the control group (experiments 1 and 2) and the control visit (experiment 3) involved a time-matched, seated rest for 20 minutes. Heart rate was monitored at baseline and at the end of the protocol.

Memory Assessment

As discussed elsewhere,[27-29] memory was assessed using the standardized Rey Auditory Verbal Learning Test. Participants listened to and immediately recalled a recording of a list of 15 words (list A) 5 times in a row (trials 1-5). Each word list was recorded at a rate of approximately 1 word per second. Participants then were asked to listen to and immediately recall a list of 15 new words (list B). Following this, participants recalled as many words from list A as possible (trial 6).

Retroactive interference was assessed by comparison of the immediate delay list A recall after list B (ie, trial 6 of list A) and recall of trial 5 for list A (ie, list A trial 6–list A trial 5). That is, the trial 6–trial 5 difference score served as the measure of retroactive interference.

Table 1. Characteristics of the Sample.[a]

Variable	Experiment 1, Walking—Between-Subject	Experiment 2, Jogging—Between-Subject	Experiment 3, Walking—Within-Subject
Age, mean years	25.2 (3.9)	22.0 (2.3)	20.9 (1.9)
Non-Hispanic white, %	65.9	61.4	79.2
Female, %	40.9	65.9	66.6
Body mass index, mean kg/m^2	25.7 (5.1)	24.2 (4.4)	26.1 (4.9)
MVPA, mean min/wk	-	258.4 (203.5)	118.3 (96.3)

Abbreviations: MVPA, moderate-to-vigorous physical activity; -, not evaluated.
[a]Values in parentheses are standard deviations.

Analysis

As implemented in JASP (0.9.1.0), independent samples t tests (experiments 1 and 2) and a paired t test (experiment 3) were used to evaluate differences in retroactive interference (trial 6–trial 5) across the exercise and control condition(s). Independent samples t tests (experiments 1 and 2) and a paired t test (experiment 3) were also used to compare heart rate differences between the exercise and control condition(s). Using a random-effects model, Comprehensive Meta-Analysis software was used to evaluate the effect sizes between the 3 experiments. The degree of heterogeneity of the effect sizes was evaluated with the Cochran Q statistic, while the proportion of variation attributable to between-study heterogeneity was evaluated with I^2 index. Statistical significance was set at an α of .05.

Results

Table 1 displays the demographic and behavioral characteristics of the participants in the 3 experiments. Table 2 displays the physiological (heart rate) responses to the exercise protocols across the 3 experiments. For each experimental study, heart rate was statistically significantly higher ($P < .001$) at the end of the exercise bout when compared to immediately before exercise as well as when compared to the control scenario.

Table 3 displays the retroactive interference scores across the 3 experiments. Across all 3 experiments, there was a smaller retroactive interference effect (ie, smaller trial 6–trial 5 difference) after the exercise bout, when compared to the control scenario. These smaller retroactive interference effects were not statistically significant; however, these smaller retroactive interference effects approached statistical significance for experiment 1 ($P = .08$) and experiment 2 ($P = .11$), but not experiment 3 ($P = .33$). The individual data collapsed across all 3 experiments are shown in Figure 1. The meta-analytic results are shown in Figure 2. The pooled effect size (standard difference in means: −0.35; 95% confidence interval: −0.64 to −0.06) across the 3 experiments was statistically significant ($P = .01$). There was no evidence of heterogeneity, $Q(2) = 1.08$, $P = .58$, $I^2 = 0\%$.

Table 2. Heart Rate Responses Across the Conditions.[a]

Variable	Experiment 1, Walking—Between-Subject		Experiment 2, Jogging—Between-Subject		Experiment 3, Walking—Within-Subject	
	Exercise	Control	Exercise	Control	Exercise	Control
Baseline heart rate, mean bpm	71.7 (12.8)	68.2 (12.8)	71.5 (11.0)	73.0 (10.8)	86.8 (24.2)	85.5 (17.6)
Endpoint heart rate, mean bpm	110.5 (17.1)	70.3 (10.1)	182.5 (11.2)	73.7 (9.1)	127.5 (16.9)	87.0 (13.7)

Abbreviation: bpm, beats per minute.
[a]Values in parentheses are standard deviations.

Table 3. Memory Scores Across the Experimental Conditions.[a]

Variable	Experiment 1, Walking—Between-Subject		Experiment 2, Jogging—Between-Subject		Experiment 3, Walking—Within-Subject	
	Exercise	Control	Exercise	Control	Exercise	Control
Trial 5, mean # words	13.54 (1.5)	13.31 (1.3)	12.86 (1.4)	12.04 (1.7)	13.17 (1.9)	12.38 (2.2)
Trial 6, mean # words	12.54 (1.7)	11.59 (1.9)	11.40 (1.9)	9.77 (2.0)	12.21 (2.6)	10.92 (2.7)
Trial 6–trial 5, mean # words	−1.00 (1.3)	−1.72 (1.3)	−1.46 (1.3)	−2.27 (1.9)	−0.96 (1.4)	−1.46 (1.8)
Test statistic	$t = 1.78$, $P = .08$		$t = 1.62$, $P = .11$		$t = 0.99$, $P = .32$	
Effect size (95% CI)	−0.54 (−1.14 to 0.07)		−0.49 (−1.09 to 0.11)		−0.20 (−0.61 to 0.20)	

Abbreviation: CI, confidence interval.
[a]Values in parentheses are standard deviations.

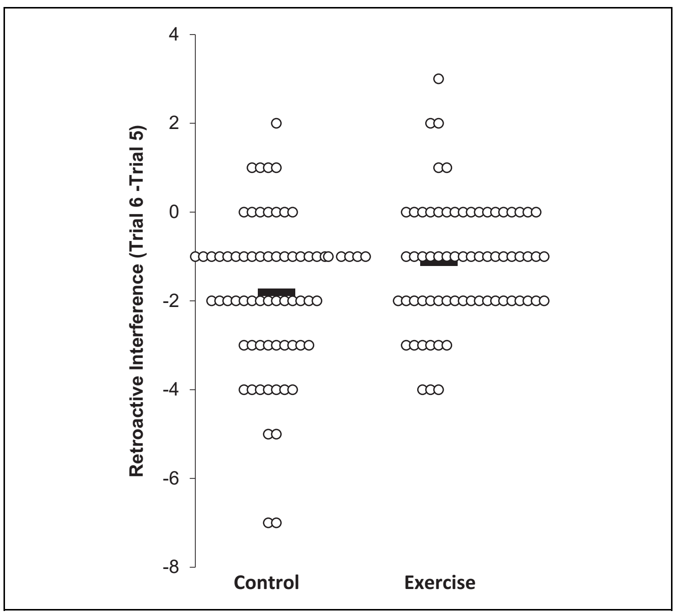

Figure 1. Individual and mean retroactive interference scores (trial 6–trial 5) across the control and exercise groups. Data are inclusive of all 3 experiments.

Discussion

An accumulating body of work demonstrates that exercise, including both acute and chronic, may subserve memory function. Within this domain, emerging work has started to evaluate whether exercise can attenuate a memory interference effect. To date, only 3 published studies have evaluated this possibility, most of which have examined proactive interference as opposed to retroactive interference. The present experiment extends this novel line of inquiry by experimentally evaluating the effects of acute exercise on retroactive interference. Across the 3 experimental studies discussed in the present article, varied by exercise intensity level and study design methodology, we provide some suggestive evidence that acute exercise may attenuate a retroactive interference effect.

Our previous experimental work provides some suggestive evidence that acute exercise, including both moderate and vigorous intensity, may help to attenuate a proactive interference effect.[23,24] Following these studies, we evaluated a 6-arm experimental trial, which included the evaluation of acute moderate-intensity exercise on proactive interference and retroactive interference. For example, the 3 retroactive interference arms included either an exercise + retroactive interference group, retroactive interference only group, or a control group (no retroactive interference). We demonstrated that the exercise + retroactive interference group recalled more words than the retroactive interference only group, suggesting a potential retroactive interference attenuation effect from acute exercise. However, there was no difference between exercise + retroactive interference and the control group, which induces some caution in the interpretation of the observed differences between the exercise + retroactive interference and retroactive interference only groups. The present experiment helps to provide additional clarity on the potential relationship between acute exercise and retroactive interference. In the present study, all 3 experiments provided some suggestive evidence of a retroactive interference

Study name	Std diff in means	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
Experiment 1	-0.537	0.307	0.094	-1.138	0.065	-1.749	0.080
Experiment 2	-0.488	0.306	0.094	-1.088	0.111	-1.596	0.110
Experiment 3	-0.202	0.206	0.043	-0.606	0.202	-0.980	0.327
	-0.350	0.149	0.022	-0.642	-0.057	-2.340	0.019

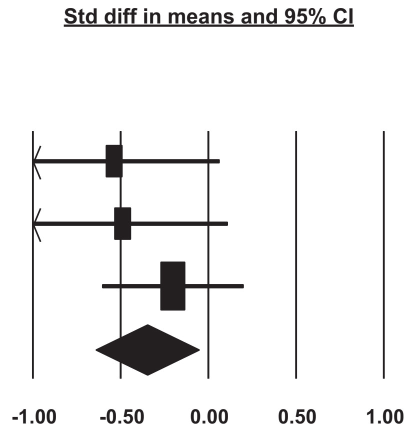

Figure 2. Effect size estimates across the 3 experimental studies.

attenuation effect from acute exercise. That is, the retroactive interference difference score (trial 6–trial 5) was smaller for the exercise condition/visit when compared to the control condition/visit.

Previous work suggests that the medial prefrontal cortex and the hippocampus, both of which are activated with acute exercise,[17,18] may help to attenuate a memory interference effect.[19-21] For example, the hippocampus not only plays an integral role in subserving episodic memory but it may also help to minimize an interference effect during the learning process.[20] When 2 stimuli (eg, list A and B) occur within close proximity of each other, the 2 memory traces may create cellular competition and in turn induce a retroactive interference effect. The medial prefrontal cortex may play an integral role in inhibiting this hippocampal-dependent interference effect via reducing the encoding of the interfering stimuli and in turn facilitating the consolidation of the initial stimuli. Further, the medial prefrontal cortex, during the memory retrieval phase, may differentially reactivate the memory traces by upregulating the activation of the initial stimuli and downregulating the activation of interfering stimuli.[19-21] We have previously detailed the mechanistic routes through which acute exercise may activate hippocampal and prefrontal neuronal activity, likely occurring through vagus nerve stimulation and peripheral muscle spindle activation.[41,42] Thus, we anticipate that acute exercise may upregulate activity of these brain regions, which in turn are responsible for minimizing retroactive interference.

In conclusion, across 3 experimental studies, we provide suggestive evidence that acute exercise may help to minimize retroactive interference. Limitations of this study include the relatively small, homogenous sample, limiting the study's generalizability. Notable strengths include the study novelty, experimental design, and integration of 3 experimental studies. Future work should evaluate potential mechanisms of this effect and continue to explore this novel line of inquiry, which may include designing exercise training studies to assess effects of chronic exercise on memory durability across several weeks or evaluating the influence of acute exercise on retroactive interference in the context of various processing demands (eg, imagery, self-referential, survival, and emotional memory cues). Continued research on this topic will elevate clinical and academic insight into the physiological and psychological conditions under which exercise may influence the durability of human memory.

SO WHAT?

What is already known on this topic?

It is well established that exercise is associated with cardiovascular function and may help to reduce the risk of cardiovascular disease. Research on the effects of exercise on brain function has also started to accumulate.

What does this article add?

Episodic memory is of critical importance for daily functioning. As such, it is important to identify health behaviors that can enhance episodic memory function. Acute exercise has been shown to enhance episodic memory recall. Here, we extend this area of research by evaluating the effects of acute exercise on attenuating memory interference, which is a known correlate of forgetting previously acquired information. Our results demonstrate that acute exercise may help to attenuate retroactive memory interference.

What are the implications for health promotion practice or research?

Health professionals should encourage individuals to engage in exercise, as such efforts may help to enhance cognition. Notably, it may be useful to engage in a brief bout of walking prior to learning information, as this may help to enhance memory retention as well as attenuate forgetting this information.

Declaration of Conflicting Interests

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