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Evaluation of Whether Habitual Physical Activity is Associated with an Attenuated Memory Interference Effect

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EVALUATION OF WHETHER HABITUAL PHYSICAL ACTIVITY IS ASSOCIATED WITH AN ATTENUATED MEMORY INTERFERENCE EFFECT

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.

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DEDICATION

This thesis is dedicated to my mother who inspired and supported me every day of her life through her advice and patience. I would not be here without her. I am forever thankful. All my love to my guardian angel.

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ABSTRACT

LILIANNE BELLE MCKISSACK: Evaluation of Habitual Physical Activity on Attenuated Memory Interference Effect

(Under the direction of Paul Loprinzi)

The relationship between exercise and memory is notable. Recently, there has been a sparked interest in studying the effects of exercise on attenuating memory interference. There have been several studies that have investigated whether acute exercise can attenuate memory interference. However, this thesis specifically studies the effects of habitual physical activity on attenuating the memory interference effect, which has been infrequently studied. One-hundred and nine young adults completed an online survey evaluating their physical activity behavior and memory interference, assessed via an AB/AC paradigm. We were effective in inducing proactive interference ($p = .001$), but physical activity was not associated with memory interference ($p > .05$). Future research is needed in this under-investigated area.

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Chapter 1

Background Information: Memory Interference

Have you ever wondered why you cannot remember where you parked your car today, and instead you are remembering where you parked it last week? Why can you remember your friend's old cellphone number instead of his or her new number? This occurs due to memory interference. Memory interference ensues from either a mechanism of passive or active forgetting (Davis & Zhong, 2017, p. 492). Passive forgetting occurs when there is not an interfering stimulus present that is causing problems with retrieval. As described above, when one fails to remember where he or she parked the car, there is not an interfering stimulus preventing the person from remembering where the car is parked. Rather, the memory trace (and its related biological materials) may have decayed, precluding the ability to retrieve the memory. Thus, without an interfering stimulus, this is considered passive forgetting. The mechanism of active forgetting requires a stimulus interfering with the consolidation required to stabilize memories. Active forgetting is triggered through external or internal factors. Various active processes have been described to explain forgetting, including retrieval-induced forgetting, directed forgetting and interference-based forgetting. The focus of this thesis is on interference-based forgetting.

Most of the information we learn in our lifetime is not consolidated to our long-term memory and is forgotten over time. Forgetting occurs at a faster rate when memory interference is involved. Memory interference occurs when competing information makes it difficult to retrieve previous or new information (Davis & Zhong, 2017, p. 491). There are three types of memory interference: concurrent interference, proactive interference, and retroactive interference. According to Hazeltine et al. (2002), concurrent interference occurs in dual task situations. When a person is performing two tasks of similar nature at the same time, there is a noticeable decline in the execution of the two tasks compared to completing the tasks individually. Proactive interference occurs when previously acquired knowledge inhibits the learning of new information. Crawford et al. (2020) suggests that this type of interference renders difficulty in learning and retaining new knowledge. There are many common examples of proactive interference that occur daily. For example, when one receives a new phone number from a friend but can only remember his or her old number. Another example occurs when an individual receives a new puppy, but frequently calls the new puppy his or her old dog's name. Retroactive interference, on the other hand, is the direct opposite of proactive interference. Retroactive interference occurs when new information inhibits the recall of old information. A common example of retroactive interference happens when an individual learns a second language and this new language begins to interfere with the ability of remembering the previously learned language. Another example of retroactive interference takes place when a person learns more advanced school subjects, which makes it harder to remember the foundational school subject(s). An example of this occurs when a senior in college who took biochemistry the previous semester remembers more biochemistry than general chemistry, which he or she took their freshman year.

Measuring Proactive and Retroactive Interference

Researchers measure proactive and retroactive interference by using various methodologies, most notably paired associate learning tasks (Crawford and Loprinzi, 2019). These tasks are typically comprised of lists of word pairs or figure pairs (e.g., "bread knife"). Research participants memorize lists of the word or figure pairs and subsequently recall them (e.g., bread - ___) (Crawford et. al., 2019). To measure memory interference using a paired-associative AB-DE AC-FG paradigm, participants will learn List 1-word pairs (AB-DE), List 2-word pairs (AC-FG), and then complete a modified-modified free recall test. The "A" words are repeat words (e.g., AB "door – leg", AC "door – tree"), causing memory interference. From the modified-modified free recall, proactive interference is calculated by subtracting the percentage of FG pairs recalled from the percentage of AC pairs recalled; retroactive interference is calculated by subtracting the percentage of DE pairs recalled from the percentage of AB pairs recalled. Lower memory interference values represent greater (worse) memory interference.

Reasons, Theories, and Mechanisms for why Memory Interference Occurs

Memory interference typically occurs with competing information. Interference occurs more often if the information is similar in nature. A common theory that explains memory interference is known as the Temporal-Distinctiveness Theory. This theory focuses on how information recollection depends on the time isolation that occurred between information (Crawford et al., 2020, p. 5). This theory states that the less time that is presented between items, the more likely interference is to occur. Thus, if one is learning information and has five minutes to process the information before subsequent learning, then this person may be more likely to have memory interference compared to another person who is given thirty minutes to process the same amount of information. Another theory used by researchers to explain memory interference is known as The Dual Mechanisms of Control Theory (Crawford et. al., 2019). This theory states that there are two mode processes that respond to memory interference: proactive and reactive control. Proactive control modes occur when information is maintained in the memory areas of the brain for a specific length of time before interference is introduced. Retroactive control mode happens after interference is already present (Crawford et al., 2020). Another set of theorists argue that retroactive interference may be misidentified when a person has simply forgotten the previous information.

Pattern separation is vital to reducing memory interference (Crawford et al., 2020, p.7). Madar et al. (2019) states, “Pattern separation is a process that minimizes overlap between patterns of neuronal activity representing similar experiences.” The brain structures of the hippocampus and the medial prefrontal cortex are known to help with pattern separation. As stated previously, memory interference commonly occurs when there is competing information. Pattern separation helps the brain to organize the two similar thoughts into two separate ideas. This allows the memory structures of the brain to properly store, encode, and retrieve the information when needed. Through research, it has been shown that the hippocampus helps to encode memories from short-term to long-term memory (Kumaran, 2008, p. 3838). Mechanistically, there is evidence of communication between the amygdala and the hippocampus in assisting with pattern separation of emotional memories. This has been observed through research studies showing stronger correlation with images that impact emotions more than neutral images (Zheng et al. 2019). When the hippocampus and amygdala are both activated, there is more pattern separation and correct recall of the images than if it was a neutral image that did not activate the amygdala.

Exercise may help to facilitate memory function and attenuate memory interference via several potential mechanisms. This paper is specifically studying how habitual exercise may possibly play a role in attenuated memory interference. Exercise may accomplish this by increasing neural activity in key brain regions involved with pattern separation. Further, exercise may attenuate memory interference by increasing neurogenesis and functional connectivity by enhancing white matter integrity in the tracts that connect these structures (Crawford et al. 2020, p.7). There have been several research studies correlating acute exercise and its role in attenuating memory interference (Johnson et al, 2019). However, there have been limited studies on habitual exercise and its role in memory interference. By doing more research, scientists will learn the effects of habituated exercise on attenuated memory interference. Using the previously explained measurements of proactive interference and retroactive interference while surveying participants for their daily exercise, researchers can learn more about the relationship between habitual exercise and memory interference.

Chapter 2:

Arguably, memory plays an important role in educational settings, occupational settings, and social interactions, as well as independent living and health outcomes. Memory based research has recently expanded to the physical exercise domain. There are numerous physiological benefits (e.g., improvement in cardiorespiratory fitness) from exercise (Mandolesi et al., 2018). Research now indicates numerous brain-related benefits from exercise, such as the hippocampus and other brain regions increasing in size with exercise (Erikson et al., 2011). Since the hippocampus helps with memory function, researchers began to study memory and exercise together. According to Gomez-Pinilla and Hillman (2014), "The hippocampus, a structure that has a fundamental role in memory processing is one of the main brain regions influenced by physical activity." The field of exercise and memory interference began in the 1960s - 1970s when researchers started realizing how important memory and exercise were for daily function. Several recent studies have demonstrated that acute exercise can attenuate memory interference (Crawford et al., 2020). Acute exercise is defined as "one bout of exercise" while chronic or habitual exercise is defined as "repeated bouts of exercise" (Sellami et al., 2019). To help move the field forward, it is important to evaluate if chronic and habitual exercise can also attenuate memory interference.

One published acute exercise study "provides suggestive evidence that an acute bout of moderate-intensity exercise can attenuate a proactive memory interference effect" (Johnson et al., 2019). It did not, however, provide evidence in support that acute exercise can attenuate retroactive memory interference effects. Crawford et al. (2020) discussed several potential mechanisms for how habitual exercise may attenuate memory interference. They indicate that chronic exercise leads to "hippocampal neurogenesis, which induces pattern separation, attenuated memory interference, and reduced forgetting." Thus, there is plausibility through which chronic exercise may help attenuate memory interference. However, limited research has evaluated the extent to which chronic exercise can attenuate both proactive and retroactive memory interference, which is the purpose of this study.

<u>Chapter 3:</u>

Participants

This study consisted of 109 American participants, aged 18-35, recruited through convenience-based sampling. The participants met the following requirements: no learning disorders (Ilieva, Hook, & Farah, 2015) and no concussions within the last thirty days (Wammes, Good, & Fernandes, 2017). This study was approved by the Institutional Review Board at the University of Mississippi and participants provided consent prior to participation.

Study Design

For this experiment, we used a Qualtrics Survey that was finalized on January 29, 2021. We, then, sent out the Qualtrics link via email to participants for completion of the study. Undergraduate and graduate students in the Department of Health, Exercise Science and Recreation Management at the University of Mississippi were recruited to participate. The study required the survey to be taken on a computer. We collected data for two weeks. We ended data collection on February 15, 2021. At this point, we began to analyze the data that had been collected.

Memory Protocol

This experiment used the AB/AC paradigm with DE/FG as respective control pairs (Crawford & Loprinzi, 2019). Two different lists were used in this experiment. Each list included eight different word pairs, four of the pairs being interference and the other four being control pairs. The words that are repeated are the “A” words (i.e., AB= Coffee- Anchor; AC= Coffee-Jacket), while the other pairs of words did not repeat. See Table 1 below for an illustration of the AB/AC memory task.

The word pairs were shown in a random order for each participant. Each of the eight-word pairs displayed for five seconds (List 1), followed by a distracting arithmetic task (after the last word pair) that lasted twenty seconds. Then, the next eight-word pairs (List 2) displayed for five seconds each with a twenty second simple arithmetic task following those words. Participants then completed a "modified-modified free recall" (MMFR; Barnes & Underwood, 1959), which allowed List 1 and List 2 to be tested together. In this MMFR, participants were cued with the first word and were asked to respond by writing the word(s) that were paired with the cued word. As shown in Table 1, the MMFR included 12 cued-recall responses. Through this recall, proactive interference and retroactive interference were tested; AB and AC are interference pairs, while DE and FG are control word-pairs. If an individual performs better on control words (which can be expected), their interference score will be negative, meaning they experienced interference. A positive interference score indicates that the individual did not experience interference and therefore they performed better on the interference word-pairs. A score of zero for proactive interference and retroactive interference indicates the participant performed equally well on the interference and control pairs and no interference occurred. Proactive interference was calculated as AC-FG, whereas retroactive interference was calculated as AB-DE. For both lists, words were drawn from the Toronto Word Pool, with each word having an imagery score of 6 or higher (Friendly et. al., 1982).

Table 1. Sample Illustration of the AB/AC Memory Interference Task

List 1 AB, DE	List 2 AC, FG	MMFR AB, DE, AC, FG
Canoe – Garden	Ocean – Echo	**Coffee – Anchor, jacket**
Hero – Apple	**Hero – Project**	Detail – Silver
Coffee – Anchor	Patent – Orange	Ocean – Echo
Detail– Silver	**Uncle – Climate**	**Uncle – Triumph, climate**
Author – Finger	Number – Fever	Patent – Orange
Uncle – Triumph	Model – Hotel	Insect– Singer
Theater – Baby	**Coffee – Jacket**	**Author – Finger, Object**
Insect – Singer	**Author – Object**	Number – Fever
		Canoe– Garden
		Hero – Apple, Project
		Theater – Baby
		Model – Hotel

Physical Activity Assessment

After the participants completed the memory protocol of the survey, they answered a series of questions related to their physical activity behavior, assessed from the Global Physical Activity Questionnaire, which has demonstrated evidence of reliability and validity (Cleland et al., 2014; Irlbacher et al., 2014). The different physical activities evaluated included: biking, swimming, fitness classes, running/ jogging/treadmill, hiking/ walking, soccer, weight lifting/ resistance exercise, dance, tennis, handball, cheerleading/ gymnastics, basketball, football, or other. This physical activity survey was modeled after the National Health and Nutrition Examination Survey and is based on the Global Physical Activity Questionnaire.

During this section of the survey, participants were asked about his/ her participation in the fourteen individual activities listed by answering “yes” or “no” to whether they engaged in the activity. If the participant selected “yes” for participating in an activity, then he/she were prompted to report the number of days and minutes per day in which they engaged in moderate-to-vigorous intensity physical activity (MVPA) for that activity. Weekly engagement in MVPA, for each of the 14 activities, was calculated by taking the product of their "days" and "minutes" response. Table 2 provides an illustration of the physical activity assessment.

Table 2: Physical Activity Measurement

	Do you participate in this activity?		On average, how many days per week did you engage in moderate to strenuous exercise for the specific activity?	On average, how many minutes per day do you engage in moderate to strenuous exercise at this level (e.g. 5, 20, 60, 90,...)? Enter 0 if you did not do this activity.
	Yes	No		
Biking				
Swimming				
Fitness Classes				
Running/ Jogging/ Treadmill				
Hiking/ Walking				
Soccer				
Weightlifting/ Resistance Exercise				
Dance				
Tennis				
Handball				
Cheerleading/ Gymnastics				
Basketball				
Football				
Other				

Quality Control Protocol

After completing the physical activity section, participants were asked if they currently smoke, consumed any alcohol in the twelve hours prior to completing the survey, consumed any caffeine in the three hours prior to completing the survey, or participated in exercise in the three hours prior to completing the survey. The participants were also asked about their focus during the survey to make sure accurate data was received. By including these questions in the survey, it allowed us to gather more data regarding these various activities, which may potentially influence memory function. An example of the concentration/focus questions asked in the survey are shown in Table 3.

Table 3: Concentration/Focus Questions

Concentration/Focus

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
It was hard for me to concentrate during the memory test.	○	○	○	○	○
I had trouble focusing my attention during the memory test.	○	○	○	○	○
I had difficulty blocking out distracting thoughts during the memory test.	○	○	○	○	○

Analyses

A Spearman rho correlation analysis was used to evaluate the association of MVPA (expressed as minutes per week) with proactive/retroactive memory interference. Separate correlation analyses were computed for proactive and retroactive memory interference and separate analyses were computed for each of the modalities of exercise. Initially, our analytical plan was, for the exercise modalities that were statistically significantly ($p < .05$) associated with memory interference, include them in a repeated measures ANOVA (rmANOVA) that involved three factors: (1) List (two levels: List 1 vs List2), (2) Interference/Non-Interference (two levels: Interference vs. Non-Interference), and (3) Meeting Exercise Guidelines (two levels: Meeting vs. Not Meeting Guidelines), defined as ≥ or < 150 min/week. However, none of the exercise modalities were associated with memory interference, so, to evaluate the memory interference results, a two factor rmANCOVA was used, including two within-subject factors: (1) List (two levels: List 1 vs List2), (2) Interference/Non-Interference (two levels: Interference vs. Non-Interference).

Chapter 4:

Characteristics of the sample are shown in Table 4. Participants, on average, were 22 years of age, with the sample being predominately female (78.0%) and white (87.2%). The mean body mass index of the sample was 25 kg/m^2.

Table 4

Descriptive Statistics

	Age	BMI	Gender	Ethnicity
Average	22.370 (SD = 2.97)	25.727 (SD = 6.29)	78% Female 24% Male	87.2% White 5.5% African American 4.6% Asian 1.8% Hispanic 0.92% Native Hawaiian

BMI, body mass index

Physical activity estimates, across each of the exercise modalities, is shown in Table 5. Across these exercise modalities, the lowest to highest weekly MVPA per week (min), respectively, occurred for cheerleading (2.75), football (2.75), swimming (5.37), soccer (5.58), tennis (7.71), biking (10.55), dance (12.73), other (15.22), basketball (27.61), fitness classes (28.81), running (72.04), weightlifting (105.14), and walking / hiking (173.51).

Table 5

Physical Activity Estimates

Physical Activity	MVPA per week
Cheerleading	2.75 (SD = 18.95)
Football	2.75 (SD = 23.64)
Swimming	5.37 (SD = 19.22)
Soccer	5.00 (SD = 36.63)
Tennis	8.00 (SD =50.60)
Biking	10.55 (SD =37.63)
Dance	12.60 (SD = 53.87)
Basketball	14.00 (SD = 59.60)
Fitness Classes	28.81 (SD = 80.30)
Running	72.04 (SD = 98.41)
Weightlifting	86.10 (SD = 147.00)
Walking / Hiking	173.51 (SD = 175.03)

MVPA, moderate-to-vigorous physical activity (per week)

Table 6 displays the memory results. The mean (SD) proportion values of AB, DE, AC, and FG, respectively, were 0.408 (0.348), 0.424 (0.331), 0.149 (0.218), and 0.365 (0.296). In a 2 (List: List 1 vs. List 2) x 2 (Interference vs. Non-Interference) rmANOVA, we observed a significant main effect for List, $F(1, 108) = 44.34$, $p < .001$, $\eta^2 = .14$, and main effect for Interference/Non-Interference, $F(1, 108) = 43.67$, $p < .001$, $\eta^2 = .07$, which was qualified by a List x Interference/Non-Interference interaction, $F(1, 108) = 29.35$, $p < .001$, $\eta^2 = .06$. The interaction was investigated with separate Tukey corrected comparisons of List for each Interference/Non-Interference level. List 1 Interference (AB accuracy) was not different than List 1 Non-Interference (DE accuracy), $p = .92$, suggesting no evidence of retroactive interference. However, List 2 Interference (AC accuracy) was worse than List 2 Non-Interference (FG accuracy), $p < .001$, demonstrating evidence of proactive interference. We also computed sensitivity analyses (rmANOVA) that controlled for each of our quality control measures (smoking, alcohol, caffeine, exercise prior to the memory task, and their concentration and distraction during the memory task), but these rmANCOVA analyses produced the same pattern of results from our rmANOVA, i.e., significant List x Interference/Non-Interference interaction.

Table 6

Memory Proportion Results

	AB Value	DE Value	AC Value	FG Value
Mean	0.408	0.424	0.149	0.365
Std. Deviation	0.348	0.331	0.218	0.296

Table 7 displays the correlation matrix depicting the relationship between weekly engagement in MVPA for each of the 13 exercise modalities with PI and RI. As shown in Table 4, the correlation coefficient (Pearson) ranged from -.11 to .15. All correlation coefficients were not statistically significant, all *p*s > .11.

Table 7

Correlation Matrix (Spearman rho correlation coefficients) depicting the relationship between each exercise modality (minutes per week) and RI and PI.

Exercise	RI	PI
Biking	.14 (.14)	.04 (.66)
Swimming	-.11 (.25)	.08 (.43)
Fitness	.11 (.25)	-.02 (.77)
Running	.08 (.38)	.13 (.17)
Walking/Hiking	.12 (.23)	.05 (.63)
Soccer	.01 (.94)	-.05 (.59)
Dance	.12 (.23)	-.07 (.44)
Tennis	.19 (.05)	.07 (.49)
Handball	N/A	N/A
Cheerleading	-.09 (.38)	-.02 (.84)
Basketball	.09 (.37)	-.002 (.98)
Football	.005 (.95)	-.02 (.84)

Note. N/A, not applicable; no participants engaged in this modality of exercise. Values in parentheses are *p*-values. PI, proactive interference. RI, retroactive interference.

Chapter 5:

Since the psychological field of exercise and memory began in the late 1960s, there have been numerous studies that have helped to expand the field. Several recent studies have explored the relationship between acute exercise and memory interference (Crawford et al., 2020). Yet, the relationship between habitual exercise on attenuating memory interference has yet to be studied in-depth. This thesis work allowed us to explore new ideas in the field of memory interference and exercise by studying the association of chronic habitual exercise on attenuating retroactive and proactive memory interference. Through this study, we were able to effectively induce proactive interference, but not retroactive interference. Further, we did not detect an association with any exercise modality on memory interference (either proactive or retroactive).

Even though this data is different from my original hypothesis of chronic habitual exercise helping to attenuate both retroactive and proactive interference, this experiment provided us with invaluable data that can be used in future experiments. According to Crocco et. al., proactive interference is showing to be a common occurrence for early diagnosis with Alzheimer's Disease (2014). Thus, by this experiment showing our task can induce proactive interference, it has possible implications of being used as an early detection measure for cognitive impairment.

Despite this experiment being one of the first to look at habitual exercise on memory interference as a whole, there have been a handful of studies that have looked at exercise on proactive memory interference by itself. In one study by Suwabe et al. (2017), young adult human participants were asked to perform acute exercise prior to completing a mnemonic discrimination task. This task involves showing participants a series of images. The participants then rested for 45 minutes and then were shown another series of images. Some of the images were new and some were from the previous set. Participants were then asked to verify which images had been in both sets. The participants who participated in high amounts of aerobic exercise had better discrimination of the new items that were visually similar to some of the studied items (i.e., similar lures). Thus, this experiment showed that acute exercise, relative to control, was effective in attenuating proactive memory interference. Another study by Heisz et al. (2017) studied proactive interference with chronic exercise by having older adults engage in exercise for 20 minutes, three times a week for six weeks. This study also used a mnemonic discrimination task. This experiment showed that chronic exercise training was effective in attenuating proactive memory interference.

A study by Wingate, Crawford, Frith and Loprinzi (2018) evaluated the effects of walking for 15 minutes prior to completing an AB / AC word list task. This experiment by Wingate showed no effect of exercise in attenuating proactive memory interference; this study is often compared to Johnson, Crawford, Zou, and Loprinzi (2019) who studied human participants running for 15 minutes before completing the AB / AC word list. The study with Johnson et al. (2019) indicated a positive effect with attenuating proactive memory interference. In an animal study, Epp et al. (2016) studied young adult mice for four weeks who performed wheel running between original and reversal learning tasks. In reverse learning tasks, animals change behaviors from a previously learned response to a new one to continue receiving reinforcement. Results showed that chronic exercise was effective in attenuating proactive memory interference.

A recent review by Li et. al. (2019) summarized the effects of exercise on proactive interference. This review evaluated 11 studies that implemented chronic exercise protocols. Looking at the prior studies on this topic, most of the researchers had the participants perform the physical activity modality before completing the task. The studies that had attenuating effects on proactive memory occurred more frequently when utilizing high-intensity exercise protocols. In contrast, studies that used lower-intensity exercise protocols (e.g., brisk walking) had no effects of exercise on proactive interference. When comparing my study to the findings in literature, I see similarities as well as differences. Previously published experiments incorporated certain cardiovascular type exercise tasks for a certain amount of time while my experiment used a self-reporting format. My experiment occurred through a remote format during the COVID-19 pandemic; I feel that my results may have been more conclusive if I had required a certain number of participants to do a specific structured exercise for several weeks instead of allowing for self-reported exercise. This would have allowed me to know actual exercise patterns and prevented over or underestimation of physical activity levels that likely occurred with my survey format. Almost every participant in my study reported that they walked for a certain amount of time daily, which made it the number one physical activity modality in my study. As discussed previously, it seems that walking is not a vigorous enough exercise to help with attenuating proactive memory interference. If this experiment was performed with specific cardiovascular type exercises for a certain amount of time over several weeks, there is a possibility for different results to occur. I imagine that my current experiment did not show an effect of chronic exercise on memory interference as it allowed for self-reporting from primarily white, female college students. If this experiment had been performed with a more random population engaging in a structured cardiovascular exercise program, for a standard amount of time, with the memory task occurring in a laboratory setting free of distractions, the results may have possibly shown a correlation between chronic exercise and memory interference.

Limitations of this experiment include completing a survey where the participants were primarily white, female college students who indicated that their main forms of physical activity were either walking or weightlifting, as seen from the recorded MVPA in Table 5. Walking and weightlifting may not have been intense enough to elicit favorable effects on memory interference. This survey was required to be taken on a laptop, but many people tried to take it on their phone resulting in incomplete data (these participants were not included in the analysis). The survey was able to be taken anywhere on a laptop, which likely means that people clicked on this survey in distracting environments and continued to take it. Taking a memory test in a distracting environment can result in errors in data. However, to address this issue, we statistically controlled for our measures of concentration and distraction in our analyses, and our results were unchanged when taking these parameters into consideration. This survey allowed for self-reporting on exercise habits, which can be problematic for accurate results. According to Brenner & DeLamater (2014), "self-reported rates of exercise… were double the actual frequency of these behaviors." Errors with survey self-reporting often occur as respondents try to answer based on what they believe the researcher is wanting for his / her research rather than the most accurate answer for the participant (Breener & DeLamater, 2016). In the future, more accurate data may occur if the survey did not allow for self-reporting on the exercise behaviors and the memory portion of the survey occurred in the same setting each time with few distractions. Despite these limitations, strengths of this study include being able to perform an exercise-based memory experiment virtually during a pandemic. Data was collected on a topic that otherwise would have been unable to be completed during the unprecedented years of 2020 and 2021. Another strength of this study was that it was very low-cost. Besides the subscription to the survey website, there were no other costs associated with this experiment. Lastly, another strength of this study was the comprehensive evaluation of different modalities of exercise, which, up to this point, has not been considered within the context of memory interference.

In the future, subsequent work should try to conduct this experiment with less self-reporting opportunities and more specific guidelines in regard to the types of exercise, the duration for the exercise, and the setting in which the memory task takes place. This experiment should also try to study various age groups and populations. This study was limited to the age range of 18-35; however, results may change with various age groups and populations. Future work should also try to understand how to induce retroactive memory interference.

Overall, in our experiment, we were effective in inducing proactive memory interference. However, none of the evaluated exercise modalities were associated with memory interference. Future work is needed to develop a better and more accurate understanding of attenuating memory interference with exercise.

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