Spring 5-10-2023

The Effects of Acute Exercise on Memory: Considerations of the Testing Effect

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Recommended Citation

Christian, Philip, "The Effects of Acute Exercise on Memory: Considerations of the Testing Effect" (2023). *Honors Theses*. 2990.
https://egrove.olemiss.edu/hon_thesis/2990

The Effects of Acute Exercise on Memory: Considerations of the Testing Effect

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

Oxford
April 2023

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ACKNOWLEDGEMENTS

I would like to first thank my advisor, Dr. Paul Loprinzi, for guiding me and dedicating his time and effort toward my project. I would secondly like to thank West Sepko, Mirai Jones, Reese Mann, and Saili Weeden for their role in assisting me with data collection. I also owe a thank you to the rest of the Exercise and Memory lab for supporting me, providing me with the resources I needed, and always being there when I needed assistance. To the University of Mississippi, the HESRM department, and the Sally McDonnell Barksdale Honors College, I could not be more grateful to have been given this opportunity. Thank you so much for everything you have done for me. Additionally, I would like to thank all of the students who dedicated their time and energy to participate in my experiment. I appreciate your flexibility working with me and am grateful for your contribution to my research. Lastly, I would like to thank our committee members, Mr. Kris Brasher and Dr. Donald Skinner.

ABSTRACT

PHILIP CHRISTIAN: The Effects of Acute Exercise on Memory: Considerations of the Testing Effect

(Under the direction of Paul Loprinzi)

This study had three main objectives. The first objective was to determine whether or not there was evidence of a testing effect being present when a short-term memory assessment is included along with a long-term memory assessment. The second objective was to determine whether acute exercise can improve long-term memory recall over a control condition. The third objective was to determine if the potential effects of acute exercise on long-term memory are confounded by the inclusion of a short-term memory assessment. Participants were 54 undergraduate students at the University of Mississippi, with an age range of 18-22 years old. Participants completed 9 visits in total. The first visit was a maximal exercise visit to determine their max heart rate, with the following 8 visits being a main exercise or control visit, with a 24-hour follow up visit for long-term memory recall. Immediately after exercise or control, the participant encoded a set of 15 words for 5 cycles. Immediately after encoding, the participant would either leave the lab or perform a short-term recall of the set of words, depending on the condition. Results of this study suggested evidence of a testing effect, that acute exercise may improve long-term memory, and that the effects of exercise on long-term memory might not be confounded by including a short-term assessment.

TABLE OF CONTENTS

LIST OF FIGURES

Chapter One: Background on Memory Systems & Exercise Influence

This chapter will introduce different memory types and discuss the potential role of exercise in improving memory. Explicit memory is a form of long-term memory defined as remembrance of information that is intentionally retrieved due to a stimulus or question. It can be divided into two subsections, including episodic memory and semantic memory. Episodic memory is much like it sounds, in that it is the recall of situations or events that have previously occurred. It has to be personally experienced by the person remembering in order to be episodic memory. This involves both the context of everything happening around the event encoded, along with the event itself (Burgess, 2002). Semantic memory is the intentional recall of concepts, ideas, or general dogma that one has learned (Jawabri, 2022). The important factor of explicit memory is the consciousness of recall. In order to be explicit, the memory must be retrieved from the brain on purpose, whether provoked or not. On the other hand, implicit memory is information that has been learned or acquired through experiences, however it is not consciously recalled when used. This can come in forms of language, sequence learning, or even muscle memory (Ettlinger et al., 2011). Implicit memory is retrieved unprovoked and is more commonly used for everyday life routines that we do not have to think about doing.

Integrated into these other two types of memory comes working memory. This is the active retention and then use of information in order to complete a cognitive function (Cowan, 2014). Working memory is used only over a shorter period of time, as it is used to complete a task that is soon to happen. A very important aspect of working memory is that the current information is actively being recalled within the brain so that information is not forgotten soon after exposure. It is often used when remembering sequences of numbers, such as phone numbers or when trying to memorize information. Despite this, working memory can become integrated into long-term memory with enough short-term practice (Cowan, 2014). These types of memory are important for cognitive functioning, so it is also important to understand the brain structures involved in integrating this information, making it possible for recall to occur.

Brain Structures & Memory

For these types of memory to become processed and input properly into the storage system, many different structures within the brain work together to make this happen. For long-term memory, hippocampus, cerebral cortex, and amygdala are important proprietors of encoding and retrieval. First, the hippocampus is where our episodic memories are created (Burgess, 2002). This tiny structure within the brain is responsible for almost all of our past memories and what we have learned from them. Without it, we would not be able to remember any recent events that have happened to us along with using them for future learning. The amygdala, located in front of the hippocampus, is responsible for the relation and remembrance of emotion associated with memories. Such that we should get scared when we see a ghost or that we are happy when we see a small animal, the amygdala is the reason these emotions are elicited. Past emotions associated with those experiences are stored within the amygdala, which then works with the hippocampus to retrieve those emotions when presented with new opportunities. This close association with recall of past experiences is what suggests a strong relationship between the two brain structures. As one is inputting information into the brain, the other is doing the action so that the two can properly react together to new stimuli. These emotional associations can be stored within our brain for a long time and can be very difficult to change (Hermans, 2014).

Phases of Memory

Memory encoding, storage, and retrieval are the ways that we interpret and use memories from our brain. Encoding is the process of gaining an initial memory and putting it into our brain. This is done constantly, every day of our lives, however it is done selectively. Encoding allows us to input important information into our storage centers and keep information deemed unimportant out. This selectivity is a very important aspect of encoding as we are not able to encode all information presented to us (McDermott & Roediger, 2014). An example of this would be remembering important information for a test but not what was for dinner every day of last week. Practicing and repeating information, such as done in working memory, can help to improve encoding. Within a study/experiment, intentional encoding is an explicit process that participants are instructed to engage in. They are asked to encode a list of words, for example, into their memory.

Memory storage is very similar to encoding; however, it deals with how we maintain memories and information over the short-term and long-term. Experiences we have alter our brains, leaving an engram (memory trace) in it. These engrams are created by the consolidation of information into our neural pathways (McDermott & Roediger, 2014). As time goes on, storage of a specific piece of information may get worse if it is not occasionally reinforced through re-encoding/retrieval. The storage of information can also be inaccurate at times, as people tend to misremember what they have seen or forget certain information that was once readily available. Stronger, long-term memories have been reinforced longer and thus stored much better than certain short-term memories. This storage of memories either in the short- or long-term then allows people to retrieve this information. For the storage of word lists, for example, during the study phase of an experiment, certain mnemonic devices or effort towards encoding could help individuals to better store the words. These mechanisms help to further entrench neural pathways with the information you are trying to store.

Memory retrieval is the process of recalling information that has been both encoded and stored within our brain's storage system. Retrieval happens through certain cues that may be conscious and direct, such as a question, or unconsciously through certain sense recognitions or other triggers. As stated above, the conscious retrieval of an event is referred to as explicit memory, while the unconscious retrieval of an event is referred to as implicit memory. Retrieval can happen within minutes of storage or years down the line; an important part is the reappearance of specific information that has been encoded and stored. This is probably the most important part of memory functions as it highlights actual usefulness of the memories we have. Without being able to retrieve information from storage, that information may be ineffective (McDermott & Roediger, 2014). Within a study/experiment, retrieval of information is important for both short- and long-term memory performance. Differences in ability to recall words, for example, may be related more to the effort an individual puts into encoding.

Exercise & Memory

Now that we have discussed the different phases of memory and various memory systems, the following text will introduce the possibility of exercise to improve memory. Exercise associations with cognitive function have been thoroughly studied and a good foundation of information has been developed for the subject (Loprinzi, Roig, Etnier, Tomporowski, & Voss, 2021). Overall, research has suggested that exercise is beneficial for cognitive function and memory overall. It has been shown that a consistent, thought-out exercise plan could be beneficial for those in need of enhancing their cognitive function, such as in older people (Saez, 2019). These findings, along with many others, have gone on to demonstrate how exercise is a beneficial tool for brain functioning. Another study in children showed that exercise was able to increase prefrontal cortex activity and increase overall brain activation (Davis et al., 2011).

The common census amongst studies done on exercise and memory is that exercise has shown to be a beneficial factor for increasing memory function, both in the short-term and long-term. One study found that participants who had exercised just prior to encoding a list of words, were able to recall more words than those who had not exercised at all before encoding (Labban & Etnier, 2018). Another found that in a seven-day recall of words, those who participated in moderate to vigorous intensity exercise before encoding words, performed significantly better during recall than those who did low intensity to no exercise at all (Pyke et al., 2020). It seems that moderate to vigorous intensity exercise is associated the most with increased memory function. A study by Frith et al. in 2017 demonstrated that vigorous intensity exercise was able to enhance long-term memory the most, while another study by Wang and Wang (2016) found that middle to high-intensity exercise had the most enhancement on long-term memory. These studies have focused on long-term memory. As for short-term memory, a similar result amongst studies is that any type of exercise, low to vigorous intensity, before encoding leads to a much better immediate recall of the words. A study in 2020 used the intervention of high-intensity interval training (HIIT) and wanted to compare how much this intervention would affect short-term memory. After the HIIT intervention over the course of three weeks, the researchers were able to find significant improvements of short-term memory as compared to those who did not participate in HIIT (Mendoza et al., 2020). This foundation of knowledge has led researchers to conclude that exercise can be helpful for improving memory and cognitive function. The following section will discuss some potential mechanisms through which exercise may influence memory.

One potential mechanism through which exercise may improve memory is through its effect on brain-derived neurotrophic factor (BDNF). BDNF is a neurotrophic factor that promotes growth and maturation of new neurons from stem cells within neural pathways and the brain (Bathina & Das, 2015). This factor may be able to increase our memory by increasing the neurological pathways that exist and deepening the information further into our memories during encoding. A study from Schmolesky et al. (2013) measured the levels of BDNF after 40 and 20 minutes of exercise and saw that BDNF circulation levels were 2.7 times higher in participants who did 40 minutes of vigorous intensity exercise as compared to the 20-minute group. Importantly, especially in animal models, exercise-induced changes in BDNF correlate with improved memory performance (Loprinzi, 2019). This benefit of an increase in BDNF is extremely important for cognitive function in general. This factor, along with others, needs to be continually studied in order to correctly determine what it is that leads to exercise improving our memories in the way that it does. The following chapter will briefly re-introduce some literature on exercise and memory and discuss a gap in the literature regarding the effects of exercise on memory. This will then lead into the purpose of my thesis experiment.

Chapter Two: Introduction

Current research is still continuing to evaluate if acute exercise can improve short-term and long-term memory. A recent study found that there were repeatable results of high-intensity exercise being able to improve long-term and short-term memory through all three mechanisms of encoding, retrieval, and consolidation (Loprinzi et al., 2021). The exercise group was able to remember, on average, one more word in both the short- and long-term recall tests when compared to the control group. Not only does acute exercise have beneficial effects on short-term memory, but it also has improving effects on long-term memory. This can be seen in two separate meta-analyses of other independent studies, which both demonstrated that acute exercise may have important effects on long-term memory (Loprinzi et al, 2019; Roig et al., 2013). However, most of these studies that have evaluated the effects of acute exercise on long-term memory have included a short-term assessment within the same study.

Given that most of these prior studies evaluating the effects of acute exercise on long-term memory have included a short-term memory assessment in the protocol, it is possible that the effects of acute exercise on long-term memory may be driven by the effects that acute exercise has on short-term memory. And this enhanced exercise-induced improvement in short-term memory may then improve long-term memory because the act of completing a memory assessment can influence subsequent memory performance. This memory phenomenon is known as the testing effect, in which testing an individual on information before another assessment improves their memory of that content. A study was able to support this phenomenon by having two separate groups of participants. One group studied the material then was subsequently tested on that material, then tested again in two days and a week later. The other group was instructed to study then study again before being tested in two days and a week later. The study, test group had a higher recall of the material than the study, restudy group, implying that testing enhances learning and memory in the long-term (Roediger & Karpicke, 2006). So, with most of the prior research studies on exercise and memory having a short-term assessment embedded in the protocol, it is hard to judge whether or not exercise truly had an effect on long-term memory or if it was confounded by the inclusion of a short-term memory assessment.

To address this possibility, my thesis aimed to see if these short-term assessments confounded the relationship between acute exercise and long-term memory function. Using a control and exercise intervention on every participant, we had conditions that only included a long-term memory assessment, with other conditions including both a short- and long-term memory assessment. This experimental protocol allows for the testing effect to be measured within exercise and control conditions. If the effects of acute exercise on long-term memory are confounded by a short-term memory assessment, then acute exercise (versus control) should not have a greater long-term memory performance when they complete both a short- and long-term memory assessment. In contrast, if this relationship is not confounded by implementing a short-term memory assessment, then acute exercise (versus control) should improve long-term memory in conditions that include a short-term memory assessment.

Chapter Three: Methods

Participants

54 University of Mississippi students (27 female; 18-25 years) took part in this study. Participants were screened to ensure that none of the following conditions were met: (1) self-reported as a daily smoker; (2) self-reported being pregnant; (3) exercised within 5 hours of testing; (4) consumed caffeine within 6 hours of testing; (5) took medications used to regulate emotion (e.g., SSRI's); (6) had a concussion or head trauma within the past 12 months; (7) took marijuana or other mind-altering drugs within the past 2 days; (8) were considered a daily alcohol user (> 30 drinks/month for women; > 60 drinks/month for men) or consumed alcohol in the past 12 hours; or (9) answered "yes" to any of the questions on the PAR-Q (Physical Activity Readiness Questionnaire).

Study Design and Procedures

A 2 (Exercise: Control v Exercise) × 2 (Memory Assessment: LTM (long-term memory) only v STM (short-term memory) and LTM) factorial design was employed. All factors occurred as within-subject factors, i.e., all participants completed all conditions. Regarding the first factor, participants exercised at a vigorous-intensity for 20-minutes for one condition and engaged in a time-matched non-exercise control for the other condition. After exercising or control, participants encoded a series of words. After encoding, in one condition, participants completed an immediate free-recall assessment (short-term memory) followed by a 24-hr delayed free recall assessment (long-term memory), whereas in the other condition, only the 24-hr delayed free recall occurred (no short-term memory assessment). See **Figure 1** for a schematic of the study procedures.

Allocation concealment occurred by both the researcher and participant not knowing which condition the participant would complete until arriving in the lab. Randomization was performed using a computer-generated algorithm. Participants completed nine visits in total. The first visit included a maximal exercise (treadmill) test to determine the participant's maximal heart rate and to also familiarize the participant with the memory protocol. The heart rate maximum achieved during the first visit was used to set the exercise intensity for the subsequent submaximal exercise sessions. After the initial visit, eight subsequent visits occurred, including the primary and follow-up visits for each of the four within-subject conditions.

Maximal Exercise Visit (1st session)

The first laboratory visit included a maximal treadmill-based assessment. The specific assessment included an individualized protocol. Participants warmed-up for 3-min by walking at 3.5 miles per hour. Following this, they engaged in a constant speed throughout the test while the grade increased by 2% every 2-minutes. After the warm-up period, the speed was set, and remained, at 5.5 mph for the entire exercise protocol. During the maximal treadmill test, heart rate (HR) was monitored throughout the test. Rating of perceived exertion (RPE) was also evaluated (6-20 scale) at the conclusion of the bout of exercise. The maximal treadmill exercise bout ended when the participant indicated they could no longer continue exercising.

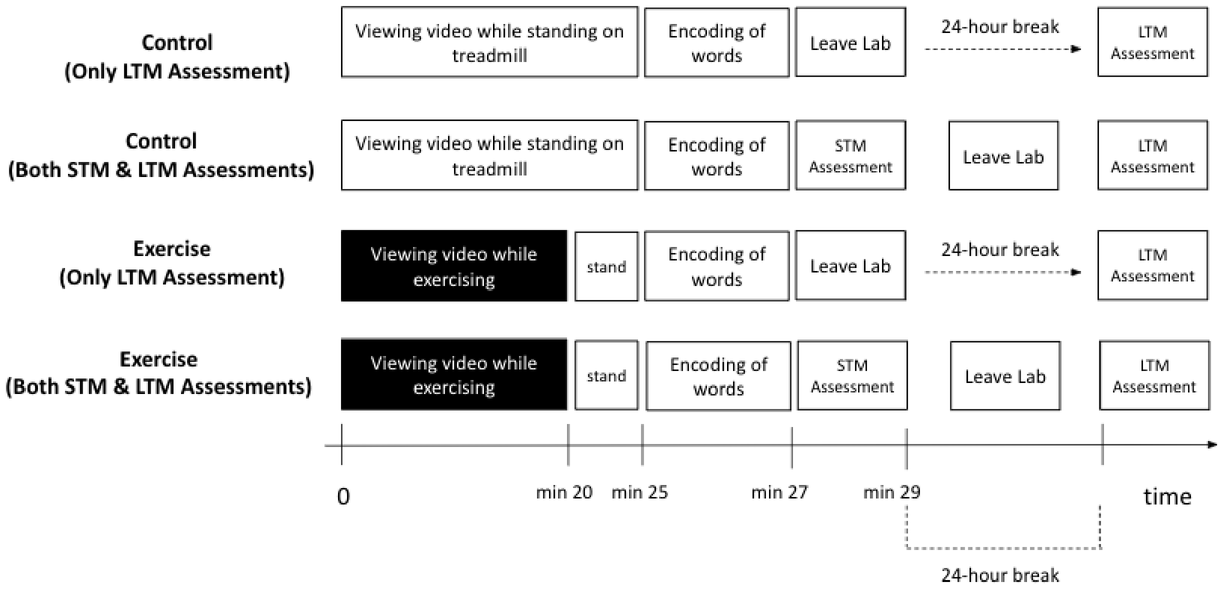
Control, Vigorous-Intensity Exercise

Participants completed two Control conditions, involving watching a video for 25 minutes while standing on the treadmill; a low arousal video (nature scenes) without volume was used. Following this, they commenced the study phase of the memory task, which took place in a seated position in an isolated unit devoid of visual distraction.

The two exercise visits involved exercising for 20 minutes at a vigorous-intensity on a treadmill. Following exercise, participants stood on the treadmill for five minutes for recovery. During both the exercise and recovery periods on the treadmill, participants watched a low arousal video (no volume). Following this 25-min period, they commenced the study phase of the memory task, which took place in a seated position in an isolated unit devoid of visual distraction.

Based on the participant's maximal heart rate achieved during their maximal exercise bout (visit 1), they exercised at 80% of their heart rate reserve. Heart rate reserve was calculated as ($[HR_{max} – HR_{rest}) * \%$ target intensity$] + HR_{rest}$). The resting heart rate measurement occurred after sitting quietly for five minutes.

Figure 1



Memory Assessment

Study List The memory task was programmed in E-Prime (v.3). Similar to common list-learning paradigms (e.g., Auditory Verbal Learning Test), participants were exposed to 5 trials, each including 15 words. The words were identical across the 5 trials, but were displayed in a random order, across trials and participants. Separate word lists were used for each of the four conditions. Each word remained on the computer screen for 1500 milliseconds and participants verbally said the word aloud as it appeared (to ensure they are processing the stimuli). Notably, this memory protocol has been shown to be sensitive to exercise-related improvements in memory (Loprinzi et al., 2021).

Each word list was created by utilizing the MRC Psycholinguistic Database from the University of Western Australia. The following criteria were set for each word: number of letters (4-10), number of syllables (1-3), familiarity rating (450-700), concreteness rating (450-700), imageability rating (450-700), meaningfulness rating (450-700), and only nouns will be used. No two words within each list were semantically related ($r < .30$). Further, a similar proportion of animate words (i.e., animates can act; grow and reproduce; know, perceive, emote, learn and deduce; and made of biological structures that maintain life) appeared in each list (Bonin, Gelin, & Bugaiska, 2014). An ANOVA demonstrated that, across the four lists, there was not a statistically significant difference for the number of letters, *F*(3, 59) = 1.16, *p* = .33, *M* (SE) = 6.05 (.16), number of syllables, *F*(3, 59) = .90, *p* = .44, *M* (SE) = 1.7 (.08), familiarity rating, *F*(3, 59) = .65, *p* = .87, *M* (SE) = 548.3 (4.4), concreteness rating, *F*(3, 59) = .18, *p* = .90, *M* (SE) = 565.1 (6.1), imageability rating, *F*(3, 59) = .34, *p* = .79, *M* (SE) = 581.2 (5.6), meaningfulness rating, *F*(3, 59) = 2.22, *p* = .10, *M* (SE) = 490.8 (4.3), and proportion of animate words, *F*(3, 59) = .09, *p* = .96, *M* (SE) = .21 (.05).

Recall Assessment Immediately after encoding the 5th trial, if their condition required a short-term memory assessment, participants were asked to verbally recall as many words as possible. After the participant recalled their final word, they were encouraged to try and recall at least one more word; this was implemented to avoid minimal effort during memory recall. The subsequent laboratory visit for the long-term memory assessment occurred 24-hours after memory encoding.

Immediately after encoding the 5th trial, if their condition did not require the completion of a short-term memory assessment, they left the lab and returned 24-hours later for a long-term memory assessment.

Statistical Analyses

No former inferential statistical analyses were computed at this point, as this is an ongoing project. Once 100 participants complete all phases of the protocol, formal analyses will be computed. Computing inferential analyses multiple times (e.g., now and then again after all 100 participants are tested) can increase type 1 error rates. For this thesis, we report the descriptive results for long-term memory performance across the four conditions for the 54 participants who have completed the study so far. A future honors thesis student will collect data on the remaining 46 participants for their thesis project.

Chapter Four: Results

From the first visit, the mean maximal heart was 194 beats per minute **(Figure 2)**. The HR responses to the four conditions are shown in **Figure 3.** In Figure 3, the circles show the results for the two control conditions and the squares show the results for the two exercise conditions. In the two control conditions, their HR stayed around 80 beats per minute (BPM). However, for the two exercise conditions, HR increased and stayed at approximately 160 BPM and then returned to about 115 BPM for the 5 min recovery period.

Figure 2

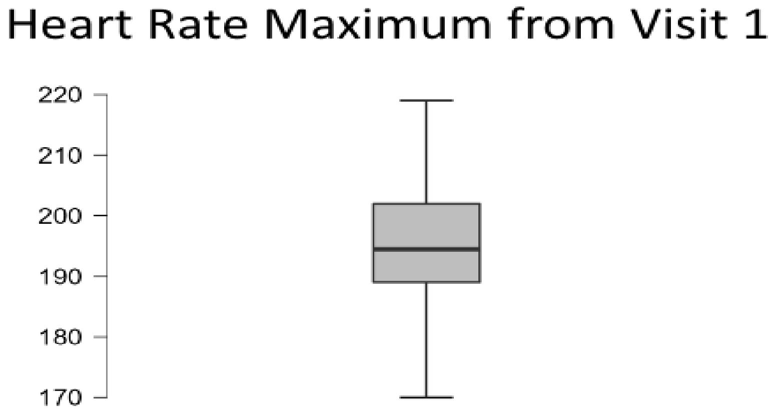
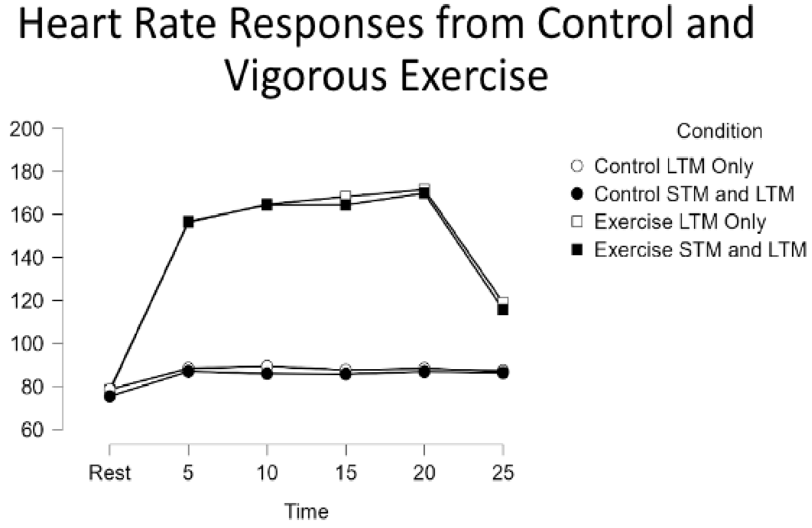
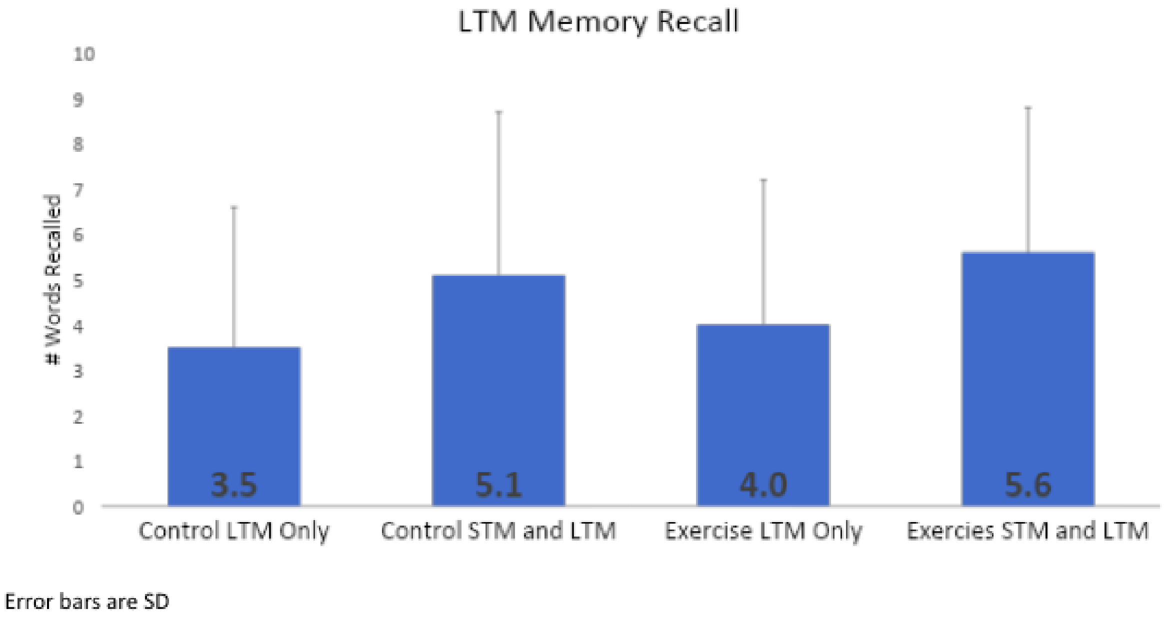


Figure 3



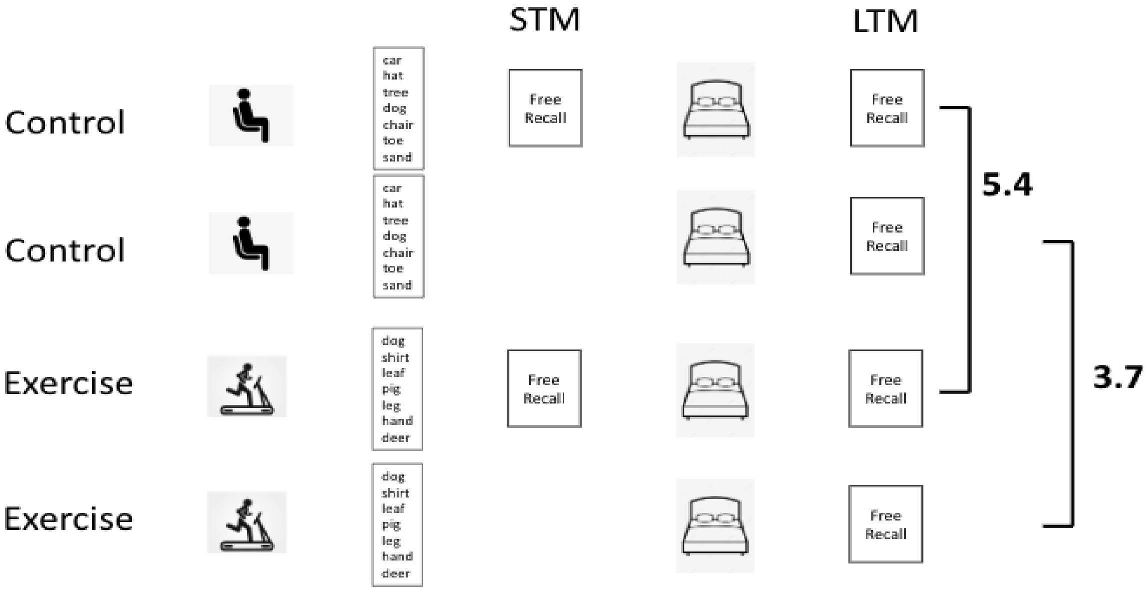
For the LTM memory results for the 4 conditions, the two conditions that included both a STM and LTM memory assessment had higher recall than the two other conditions that had only a LTM recall (**Figure 4**). Additionally, the respective exercise groups had a slightly higher recall than their respective control conditions.

Figure 4



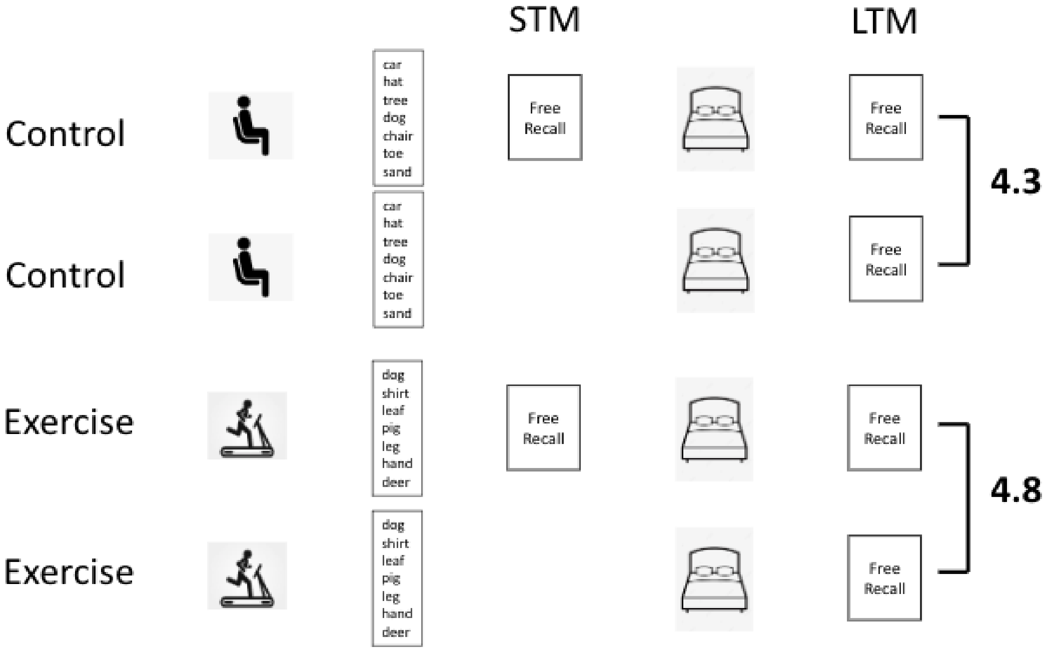
Evidence of a testing effect would occur if the conditions with both a STM and LTM memory assessment had a greater recall than the conditions that only included a LTM assessment. Our results aligned with this. The conditions with both a STM and LTM memory assessment recalled 5.4 words at the LTM period compared to 3.7 words recalled in the conditions that only included a LTM assessment (**Figure 5**).

Figure 5



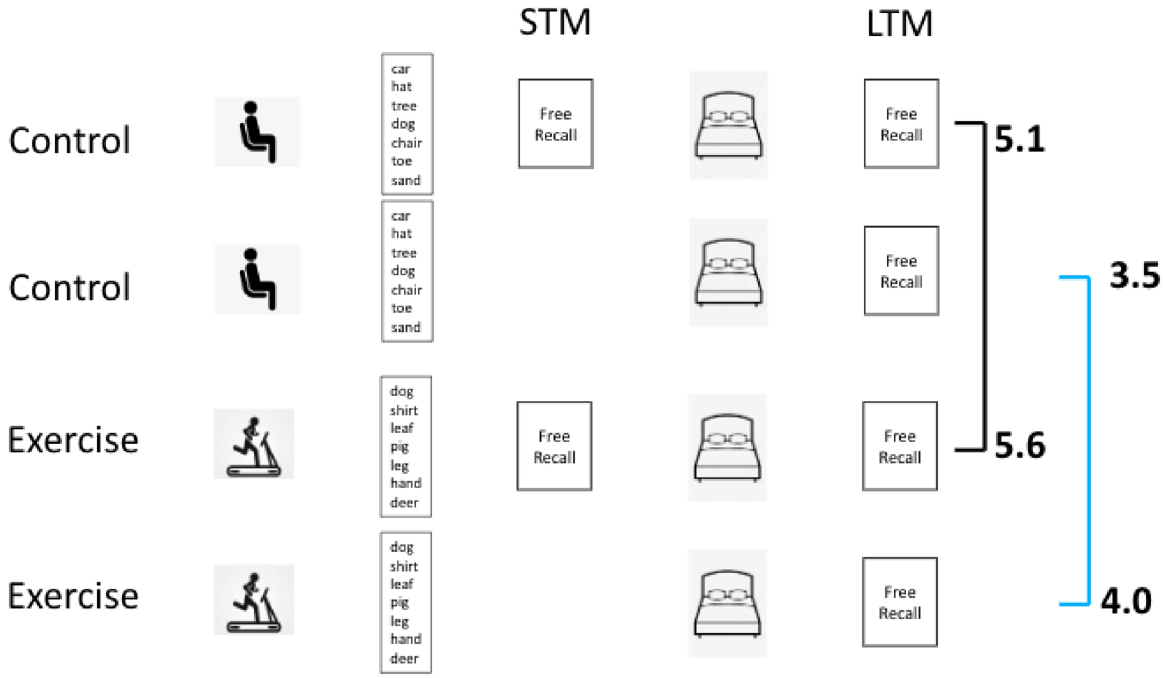
If acute exercise improves LTM over control, we would expect that LTM memory performance in the two control conditions would be lower than LTM memory performance in the two exercise conditions. Our results align with this (**Figure 6**).

Figure 6



Thus, we have some marginal evidence that acute exercise is better than control in improving LTM. If the effect of exercise on LTM is not confounded by including a STM memory assessment, then we should observe a difference between the Control STM/LTM and Exercise STM/LTM conditions. However, if the effect of exercise LTM is confounded by including a STM memory assessment, then we would only observe a difference between the Control LTM and Exercise LTM conditions. In the two conditions that involved both a STM and LTM assessment, LTM recall was greater in the exercise condition. Similarly, in the two conditions that only included a LTM assessment, LTM recall was greater in the exercise condition (**Figure 7**).

Figure 7



Since exercise was greater than control regardless of whether there was a STM assessment, the effects of exercise on LTM do not appear to be confounded by a STM assessment. These preliminary descriptive results replicate prior work showing that acute exercise may improve LTM and that the testing is very strong. Our novel experiment adds to the literature by demonstrating that acute exercise may improve LTM regardless of whether there is a STM assessment.

Chapter Five: Discussion

Within the literature there has been many research studies done on the effects of acute exercise on short-term and long-term memory. These studies often included both a short-term memory assessment of a list of items, and a long-term memory assessment on the same list of items following this short-term assessment. he presence of short-term assessments within prior studies could be the cause for improvements in long-term memory (due to a testing effect), rather than exercise being the driving factor for long-term memory improvement. Minimal research has been conducted without these short-term assessments. Our study addresses this issue by including a condition with both a short-term memory assessment and long-term memory assessment and a condition with only a long-term memory assessment (24-hour follow-up). It also had an exercise and control group for each of these two conditions to also be able to evaluate the effects of exercise on long-term memory compared to a control. Our main findings from the experiment were that there is evidence of a testing effect being present, exercise improves long-term memory over control, and that the effects of acute exercise on long-term memory is not confounded by including a short-term memory assessment.

Evidence of a Testing Effect

Our results of a testing effect being present are shown through the two conditions that have both a short-term memory and long-term memory assessment having significantly higher amounts of words recalled in the long-term memory assessment when compared to the long-term assessment only conditions. Participants recalled on average 1.7 words more for the long-term assessment when the short-term assessment was present. These findings coincide with other studies that support that having a practice assessment before a final assessment will improve performance. Specifically, seen with the Roediger & Karpicke (2018) experiment that compared the results on a final test between two separate groups, one which studied then restudied material before testing, and one that studied then took a practice assessment before testing. They were able to find that those who studied then did a practice test performed significantly better on tests 2 days and 1 week after initial encoding, than those who studied then restudied. The testing effect is effective because it forces the user to put in more effort when encoding the words and is able to reinforce the information learned from the initial study session. Here, the short-term memory assessment is seen as a learning event itself, which further consolidates those words into the participant's memory. Thus, they are able to retrieve more words when performing the long-term memory assessment.

Acute Exercise and Long-Term Memory

Next, our study was able to further establish that acute exercise may potentially improve memory performance. This was seen in the comparison between the control and exercise groups, which each had a short-term memory and long-term memory assessment condition and long-term memory assessment only condition. As seen in our results, for the exercise conditions, participants were able to recall 4.8 words on average during the long-term memory assessment. For the control conditions, participants were only able to recall 4.3 words on average, suggesting that acute exercise has a positive effect on improving long-term memory; whether this is statistically significant or not will be determined after the final set of participants are completed. Other studies have also shown that high-intensity acute exercise is effective in enhancing memory function among this young-adult population (Loprinzi et al., 2021). This improvement in memory function via acute exercise is theorized to come from alterations in neurotransmitters and growth factors that influence long-term memory consolidation (Loprinzi et al. 2019). Therefore, while there is only a half a word increase from the control to exercise group, this finding is in accordance with prior studies that included long-term memory assessments following acute exercise.

Short-Term Assessment Confounding Effects

Our final suggestion from the data is that regardless of the implementation of a short-term memory assessment, a bout of acute exercise may potentially improve long-term memory. This can be seen by the exercise conditions, compared to the control conditions, having a higher rate of long-term memory recall regardless of whether or not there was a short-term memory assessment in the protocol. For the groups that had both a short-term and long-term assessment, the exercise groups recalled half a word more than the control group. The same results were obtained for the long-term only groups with participants recalling half a word more in the exercise group compared to the control group. These findings provide some suggestive evidence that a short-term memory assessment does not confound the effects of acute exercise on long-term memory. Of course, at this point, it is uncertain as to whether these “differences” are statistically significant or not; this will be determined once the full sample is tested.

Implications

The implications of this research are that exercise effects on memory may not be confounded by including a short-term assessment. These results help to further validate previous studies that included a short-term memory assessment; thus, their findings demonstrating an improvement of acute exercise on long-term memory are likely to be a true effect and not confounded by the inclusion of a short-term memory assessment.

Strengths and Limitations

While this study does provide insight into the effects of exercise on long-term memory and the implications of including a short-term assessment within a study, there are some limitations. One limitation being the use of only college-aged participants (18-24 years old). This means that the results may not be generalizable to other populations, especially older individuals who may struggle with both exercise and memory. Doing this study with older individuals (65+) or middle-aged groups (30-55 years old) may help to apply this information to a larger population. At this point, no formal conclusion can be drawn from the information found, as we have not computed any statistical analyses to determine whether the results reached statistical significance. Thus, although we observed some notable “differences” across the conditions, we reserve caution in rendering any strong statements regarding any of these observations. Strengths of this study include the use of the same environment for every participant, the use of both a short-term and long-term recall condition and long-term only condition, the randomization of all visits for each participant along with the randomization of the four sets of words used, and a baseline exercise visit to determine the participant’s maximal heart rate. All of these components contribute to the overall reliability and validity of the study.

Conclusion

In conclusion, our study was able to provide some suggestive evidence of a testing effect, show that exercise may have a benefit on long-term memory over a control group, and the effects of exercise on long-term memory may potentially not be confounded by including a short-term assessment within a research study.

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