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The Effects of Acute Exercise and Learning Strategy Implementation on Episodic Memory Performance

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The Effects of Acute Exercise and Learning Strategy Implementation on Episodic Memory Performance

by
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Abstract

Faith Allyson Harris: The Effects of Acute Exercise and Learning Strategy Implementation on Episodic Memory Performance
(Under the direction of Dr. Paul D. Loprinzi)

Over the years, a growing body of research has shown that exercise has beneficial impacts on various types of memory function. However, most of these studies have focused on children or older adults, with less research conducted among young adults, despite research demonstrating that memory function may start to decline in early adulthood. This thesis provides background information regarding the effects of exercise on memory function, as well as different learning-based strategies to help facilitate learning and memory retention. Furthermore, the research I completed for this thesis specifically evaluated the experimental effects of acute exercise, a specific learning strategy (3-R technique), and their combined effects, on short- and long-term memory function. The results of this experiment demonstrate that memory function was enhanced, to the greatest extent, among those who engaged in an acute bout of exercise (brisk walking) and also implemented the 3-R learning technique, when compared to those who only exercised, only implemented the learning technique, or those doing neither.

Table of Contents

List of Tables and Figures

CHAPTER 1: BACKGROUND

Memory Types

Memory is important for living a high-quality life and being able to function in society. There are 3 phases of memory, which include encoding, consolidation, and retrieval. Encoding is the actual event when an individual is gaining the knowledge of information that is presented. Following encoding is the consolidation phase, which takes place at the cellular and systemic level, involving the production of proteins that allow communication between neurons and communication between the hippocampus and other neocortical areas (Loprinzi *et al.*, 2018). Memory retrieval is the action of being able to recall that memory and can be influenced by the processes of encoding and consolidation.

There are several types of memory (displayed in Figure 1 below), including sensory memory (ability to recollect sensory information), short-term memory (temporary recollection of information), working memory (short-term memory with an executive function element), and long-term memory (reflective memory). Long-term memory is broken into 3 categories: explicit/declarative memory, implicit/procedural memory, and prospective memory. Explicit, or declarative, memory involves the memory of events and facts that can be recalled consciously. Implicit, or procedural, memory is the knowledge of how to perform things. Prospective memory involves content that will be needed and remembered in the future. Regarding explicit/declarative memory, there are

2 main subtypes that follow, including episodic memory and semantic memory. Episodic memory involves the memory of experiences and events in a spatiotemporal form. Semantic memory is the trace of facts, meaning, concepts, and knowledge of the external world.

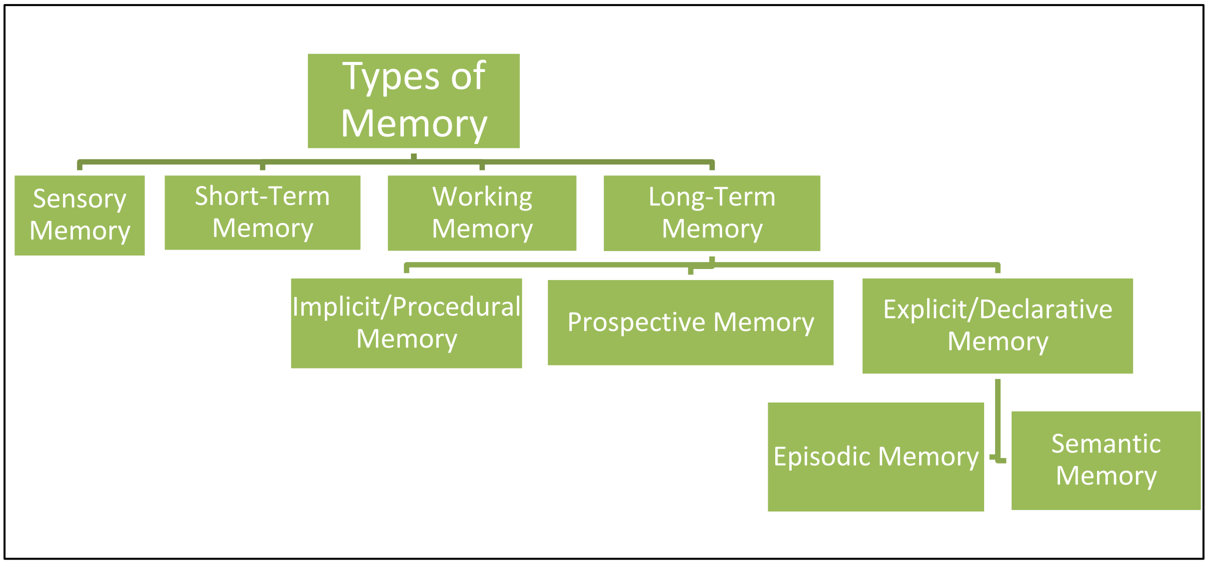

Chart 1: Types of Memory

Emotional arousal plays an important role in the memory of stimuli relevant to the situation (Loprinzi*et al.*, 2018). For example, lesions of the amygdala have shown to decrease avoidance of a highly arousing, unpleasant stimulus, like water paired with electric shock. However, the lesions did not influence the avoidance of an unpleasant but not highly arousing stimulus of bitter-tasting water. Numerous studies have shown that pairing emotions with a stimulus allows for better memory of the stimulus (Cahill *et al.*, 1995; Cahill *et al.*, 1997; Hamman *et al.*).

Mechanisms of Exercise and Memory

Knowing and understanding the mechanisms of episodic memory and how exercise may influence these pathways may lead to the knowledge of strategies that may help to maximize memory function, which would be beneficial to older adults at risk for impaired memory function (Eshkoor *et al.*, 2015).

The cellular aspect of memory is most often viewed as an engram trace, or code, that resides in specific cell assemblages (Poo *ey al.*, 2016). Current research believes that excitatory synapses located in the dendritic spines may be a vital part in the cellular aspect of memory (Poo *et al., 2016*). This suggests that a learned task will be stored in an engram cell located in the dendritic spine. Researchers believe this to be true because engram cells have shown dramatically larger dendritic spine densities than non-engram cells (Ryan *et al.,* 2015). Notably, past studies have shown that growth of dendritic spines can be facilitated by exercise (Eadie *et al.,* 2005). Furthermore, studies show that when these dendritic spines shrink in size, the information that was previously learned is forgotten (Hayashi-Takagi *et al.,* 2015). When an engram cell is reactivated by a specific cue, then memory retrieval can occur (Ramirez *et al.* 2013). With the neocortex having numerous connections, it provides the potential to retrieve the same item in memory to be retrieved via different cues (Dudai, 2004). In addition to exercise promoting dendritic spine density, exercise may be beneficial in "priming" engram cells to be candidate cells for the encoding of memories (Loprinizi *et al.* 2018). Studies show that engram cells involved in a memory trace have greater CREB levels and greater neuronal excitability prior to encoding (Yiu *et al.,* 2014) and that exercise prior to acquisition or encoding can aid in increased CREB-1 levels (Chen & Russo-Neustadt, 2009) and neuronal excitability (Cuhna *et al.,* 2010; Zoladz & Pilc, 2010). Once a task has been learned, specific engram cells will encode the memory, and this specific group of engram cells will continue to work together to collect and retrieve memories (Loprinzi *et al.,* 2018). Thus, the stronger the connections possessed between engram cells, the more likely that a pertinent cue will lead to the retrieval of memories (Loprinzi *el al.,* 2018). This property of neuronal cells is called long-term potentiation (LTP) and occurs when networks of cells are repeatedly fired, strengthening their connection. The engram serves as a cellular, physical trace of the memory, so if the memory is not fully encoded, the memory may be forgotten (Loprinzi *et al.,* 2018).

The initial phase of creating a memory trace is the encoding or acquisition phase. Encoding can take place over short or long periods of time, over single or multiple visits, and can occur in various situations or locations, and these components depend on the testing paradigm being implemented (Loprinzi *et al.,* 2018). Studies have shown that the retrieval of the memory can be influenced by the contextual factors that are present during the encoding process of that specific memory. For example, if the cues present during encoding are also present during retrieval, there is a higher chance of recall of that memory because of the 'encoding-specificity principle' (Tulving, 1983). Studies have also shown that state-dependent learning also mirrors the concept of context-dependent learning in that memory recall is optimized when retrieval and encoding occur in the same mood or attitude state (Bower *et al.,* 1978).

After encoding information, the next phase of memory is consolidation. Consolidation can take place at two levels: cellular/synaptic consolidation and brain systems consolidation. Cellular/synaptic consolidation takes places by stabilizing the memory trace, whereas brain systems consolidation involves the redistribution of the memory trace (Loprinzi *et al.,* 2018).

Memories are encoded by neurons when neurons modify the strength of their connections. The three steps of communication between neurons are: electronic conduction, action potential, and synaptic transmission. The electronic conduction phase occurs when the neuronal membrane is depolarized from the dendrite to the cell body due to an influx of Na^{+} ions. During this depolarization, the membrane potential moves from ~-70 mV towards ~0 mV. Around -55 mV, the action potential occurs. Following the action potential, the neuron goes through a repolarization phase, allowing K^{+} to flow out of the cell to balance out the Na^{+} influx, bringing the membrane back to its resting state. Most times, an action potential does not occur as the result of a single stimulus, but instead, a summation of several stimuli is used to facilitate an action potential. In regard to memory, studying for an exam for short periods of time may only cause a weak input that is not strong enough to produce potentiation of the neuron (Loprinzi *et al.,* 2018). However, exercising prior to studying may induce a stronger input, activating both the weak and strong pathways of memory and exercise (Eichenbaum, 2012).

Synaptic transmission occurs when the action potential reaches the end of the axon. Upon the arrival of the axon potential at the synaptic cleft, Ca^{+2} channels of the pre-synaptic cleft are opened and Ca^{+2} is let into the cell. The influx of Ca^{+2} allows for vesicles carrying neurotransmitters to bind and be released into the cleft between the post-synaptic and pre-synaptic membranes. At this point, LTP can occur depending on which neurotransmitter binds to which post-synaptic receptor. Receptors can be ionotropic (including AMPA or NMDA) or metabotropic.

Along with emotional arousal mentioned earlier, exercise may also impact memory through the alteration of long-term potentiation (LTP) (Loprinzi *et al.*, 2018). LTP is the process by which connections between pre and post-synaptic neurons are strengthened, allowing for encoding of memories and the acquisition of a stable memory trace. There are 2 phases of LTP: early and late. The early phase lasts a few hours and occurs when there is an influx of calcium ions into the postsynaptic membrane, causing the translocation of (alpha)-amino-3-hydroxyl-5-methyl-4-isoxazolepropionic acid (AMPA) receptors to the membrane surface. This mechanism may partially explain the influence of acute exercise on memory via early-phase LTP (Loprinzi *et al.*, 2018). Following the insertion of AMPA receptors, subsequent signals at the synapse can induce late-LTP. This phase involves a continuation of Ca^{2+} that causes signaling pathways to upregulate transcription factors that promote neurogenesis and development (e.g. Ca^{2+} uptake leads to the activation of CAMP which leads to the release of growth factors known as brain-derived neurotropic factors, or BDNF). Acute and chronic bouts of exercise have been reported to increase the expression of BDNF locally in the hippocampus (Berchtold *et al.*, 2005; Oliff, *et al.*, 1998; Knaepen *et al.*, 2010). This suggests that exercise in general promotes facets of late-phase LTP.

Additionally, increased exercise-induced LTP is believed to have a direct responsibility in memory encoding, consolidation, and retrieval. Many animal experiments have shown this repeatedly (Whitlock *et al.*, 2006; Rioult-Pedotti *et al.*, 1998). In the review by Loprinzi *et al,* several human studies also support this effect; however, most of these studies focus on children and older adults. Less attention has been brought to the potential impacts of exercise on memory function in younger and middle-aged adults. This age is the perfect time to evaluate these effects because cognitive function begins to slowly decline in the 20s and 30s (Salthouse, 2009).

Learning Strategies

In addition to exercise, using learning strategies can be helpful in improving memory function and performance. There are several different learning strategies, and this section will only touch on a few.

The 3R Technique is a popular learning strategy that stands for Read-Recite-Review (Nguyen & McDaniel, 2015). One implementing this strategy would read over the given task, recite as much as they could remember without looking at the material or text, and review the story or task once more. A modified version of the 3R technique is the SQ3R which stands for survey, question, read, recite, and review. In this practice, one would survey or skim the material to get an idea of the big picture of the material. Then, you would ask yourself questions about the material, followed by completing the 3R technique.

Use of mnemonics has been shown to be highly effective, and this includes three techniques: organization, elaboration, and visual imagery. Organization would include breaking information down and placing it into categories that are logical and sensible to you. Elaboration is assigning meaning to the information or relating it to some previous experience so that the individual can connect that memory to something relevant to them.

Visual imagery typically uses bizarre, unusual, and/or emotionally-charged imagery in order to aid in remembering the information.

Two more learning strategies are linking (or chaining) and chunking. In linking, the participant would say words they learned or remembered consecutively, and chunking would be recalling words in groups (Romani *et al.2016).* However, these techniques often employ more shallow levels of processing, and thus, are less effective when compared to mnemonic techniques that use more deep levels of cognitive processing.

Additive Effects of Exercise and Cognitive Training Combined

In a review paper by Laurenroth *et* al., studies suggest that there may be potential additive effects of combined physical and cognitive training on cognitive function. Activities of daily living (ADLs) typically require dual-tasking, and often, these tasks are very complex in their demands of motor and cognitive resources. Because of this difficulty, the dual-tasking may be harder for some people to complete, particularly elderly adults or those who may have brain pathology or disorders, according to the review from Laurenroth *et al*. However, training of physical and/or cognitive skills appears to have a positive influence on physical and mental tasks (Jak, 2012). Several studies in the review by Laurenroth *et al.* also suggest that cardiovascular and strength training improves physical aspects of a person's life, like balance, endurance, strength, and flexibility along with cognition through a chain of biological and neural mechanisms. Several studies reviewed in Laurenroth *et al*. discuss how cognitive training alone has been shown to cause greater performance in the targeted cognitive function; however, several other studies in the review paper show that the combination of physical and cognitive training allows for even better cognitive performance results than either type of training alone.

In the same systematic review completed by Laurenroth *et al.*, 20 studies were reviewed for their results based on the combined effects of physical and cognitive training on cognition. For this review, all studies contained a group that implemented an intervention of combined physical and cognitive training. 13 of these used a dual-task intervention (I-DT) (Evans *et al.,* 2009; Schwenk *et al.,* 2010; Choi *et al.,* 2015; Coelho *et al.,* 2013; De Andrade *et al.,* 2013; You *et al.,* 2009; Plummer *et al.*, 2012; Hars *et al.,* 2013; Hiyamizu *et al.,* 2012; Kayama *et al*., 2014; Marmeleira *et al*., 2009; Theill *et al*., 2013; Yokoyama *et al.*, 2015). In the 7 remaining studies, the strategy employed was a subsequent approach (I-S), where exercise and cognitive training took place consecutively (Laurenroth *et al*., 2016). In this review, 9 studies studied attention, 15 looked at executive function/working memory, and 5 evaluated episodic memory, verbal fluency, and verbal learning (Laurenroth *et al.*, 2016). Out of the 20 studies reviewed, 18 reported the combined-training groups as having enhanced cognitive performance. This review found that cardiovascular training and strength training -- when combined with cognitive training of attention and/or executive function or working memory -- seem to show better results (Laurenroth *et al.,* 2016). My research differs from this review paper in that it uses an acute learning-based strategy instead of an intensive cognitive training method. An acute learning strategy is different from the cognitive training employed in Laurenroth *et al.,* in that it is typically utilized over a short period of time, and the cognitive training typically involves the completion of a cognitive task, as opposed to implementing a learning-based strategy.

CHAPTER 2: INTRODUCTION

Exercise is important for many aspects of life, including not only physical but also mental health (Warburton *et al.,* 2006). Regarding physiological outcomes, regular exercise has been shown to reduce the risk of diabetes, heart disease, and stroke.[1] Considering mental health outcomes, exercise is inversely associated with negative psychological outcomes, such as depression (Schuch *et al.,* 2016), and is positively associated with perceived quality of life (Conn *et al.,* 2009). In addition to these outcomes, exercise has also been shown to have neuroprotective effects on the brain (Loprinizi *et al.,* 2013). For example, exercise is associated with increased neural growth factors, such as brain-derived neurotrophic factor (BDNF), which has been linked with improved global cognition and memory enhancement (Loprinzi *et al.,* 2013).

Related to this exercise-induced neuroprotective effect on the brain, research shows that exercise is favorably associated with memory function (Labban & Etnier, 2011) with effects observed across the lifespan (Voss *et al.,* 2011). There are several factors that may influence the exercise-memory relationship, such as mood-state congruency (e.g., memory retrieval is optimal when the mental state is congruent during encoding and retrieval), transfer-appropriate processing (i.e., the same cognitive strategy is used during encoding and retrieval), and the encoding-specificity paradigm (i.e., cue congruence between encoding and retrieval) (Dudai, 2004). With regard to the latter, memory function was optimized when it was tested in the same context as it was learned; for example, memory encoding and memory retrieval occurring both while walking on the treadmill (Miles & Hardman, 1998). In regard to our chosen procedure, studies show that those who exercise prior to memory consolidation shows greater memory recall than those who exercised after memory encoding, specifically during the memory consolidation phase (Labban & Etnier, 2011)

In addition to exercise potentially enhancing memory function, other factors, such as employing learning-based strategies, may further help to improve memory function. There are a variety of learning strategies which can be used for improving memory, including the 3R technique, graphic organizers, visual images paired with words, and acrostics. The 3R technique (Nguyen & McDaniel, 2016) involves reading, reciting, and reviewing the given memory task before the recall test. Graphic organizers are a more open and creative way for someone to visualize and recall the memory test. These may include organizing things into pie charts to show frequency or abundance, flow charts to show order of occurrence, and other types of organizers that may help a participant recall the information. Another learning strategy is pairing visual images with words to associate the two together when only presented with either the word or the image. Additionally, acrostics can be used to create catchy and memorable phrases to help with learning information for later recall.

We believe that employing a learning strategy coupled with exercise will have greater influences on memory function when compared to these strategies alone (i.e., an additive effect will be observed). To our knowledge, there are no studies that have conducted a side-by-side comparison as well as evaluated potential combined effects of these strategies (i.e., exercising and learning strategy) on memory function. In the present study, the specific learning strategy employed is the 3R technique. Previous studies show that using a standard 3R strategy elicits greater improvements in memory for memory-based tests, whereas improvements for inferential-based tests do not see improvement from this strategy (Nguyen & McDaniel, 2016). Regarding the exercise stimulus, this protocol will occur immediately prior to memory encoding based on previous work demonstrating that this may be an optimal time period to exercise to enhance memory function. We hypothesize that participants who exercise and then use this learning strategy will have better memory function scores when compared to those who only exercise or those only employing the learning strategy.

CHAPTER 3: METHODS

Study Design and Participants

This study employed a 4-arm parallel group randomized control trial. 80 young adult participants were recruited. These participants were then randomized into one of four groups (20 participants per group). Recruitment occurred via a convenience-based, non-probability sampling approach (classroom announcement and word-of-mouth). Participants included undergraduate and graduate students between the ages of 18 and 35. Additionally, participants were excluded if they:

Self-reported as a daily smoker (Jubelt *et al.*, 2008; Klaming *et al.*, 2016)

Self-reported being pregnant (Henry & Rendell, 2007)

Exercised within 5 hours of testing (Labban & Etnier, 2011)

Consumed caffeine within 3 hours of testing (Sherman *et al.*, 2016)

Had a concussion or head trauma within the past 30 days (Wammes *et al.*, 2017)

Took marijuana or other illegal drugs within the past 48 hours prior to testing (Hindocha *et al.,* 2017)

Are considered a "heavy" alcohol user (>30/month for women; >60/month for men) (Le Berre *et al.*, 2017)

Group Assignments

After recruitment, participants were randomly assigned into one of the following four experimental groups, which include 1) exercise and utilizing a learning strategy, 2) no exercise but does employ a learning strategy, 3) exercise but does not employ a learning strategy, and 4) no exercise and no learning strategy (control group). Specific details on each of these groups are noted in the narrative that follows.

- Group 1 (Exercise + Learning): Participants walked on the treadmill at a brisk pace (explained in detail below) for 15 minutes. Immediately thereafter, participants sat and rested for two minutes. Following the resting period, participants then applied the 3R technique to the presented memory task (explained below), and then subsequently, completed the memory task.
- Group 2 (Learning Only): Participants did not complete the exercise protocol, instead, they began their protocol by resting for 5 minutes. Following the resting period, participants then applied the 3R technique to the presented memory task, and then subsequently completed the memory task.
- Group 3 (Exercise Only): Participants walked on the treadmill for 15 minutes at a brisk pace. After exercising, the participants rested for 2 minutes and then completed the memory task.
- Group 4 (No Exercise and No Learning): Participants rested for 5 minutes and then completed the memory test.

Learning Strategy

The 3R technique stands for Read-Recite-Review. Identical to others (McDaniel *et al.*, 2009), those in the 3R group were told to read the passage (Story A; see Appendix A) once, recite as much as they could remember from the passage aloud, and then read the passage a second time. They then applied this same 3R technique to Story B (see Appendix A). Following the implementation of this technique, participants were asked to recall the information prior to a 20-minute break (short-term memory or STM) and after a 20-minute break (long-term memory or LTM). During this beak, participants watched a 20-minute video of bloopers from season 2 of the television series The Office. Research has shown that people are more likely to remember something after reading it in different ways, such as silently and aloud (Nguyen & Mc Daniel, 2016). Further, this 3R technique has demonstrated evidence of validity by showing improved immediate- and delayed-free recall when compared to other learning techniques, such as re-reading and note-taking (McDaniel *et al.*, 2009).

At the end of the study, participants rated the ease of use of this 3R technique by answering the following question using a Likert scale (strongly disagree, disagree, neutral, agree, strongly agree): “Using the 3R technique was easy for me to implement.” Using the same response options, they were asked the following question, “I felt the 3R technique was useful in helping me remember the passages from the memory tasks.” Lastly, and for comparative purposes, those who exercised were asked the following question at the end of the study, “I felt that the exercise was useful in helping me remember the passages from the memory tasks.”

Memory Task

The memory task we had participants implement was the Logical Memory Test (shown in Appendix A), which has demonstrated evidence of convergent validity with the WMS-IV (Wechsler Memory Scale) logic memory test (Schnabel, 2012). This memory task is composed of two short narrative passages (story A and story B) that are 25 lines long. Both stories consist of sequential plots with congruent content similar in length that also feature phrases intended to engage the participant's emotions.

In addition to Appendix A showing the two stories, this appendix also displays the scoring rubric for this memory task. While some words are required to receive credit, other lines only require a variation of the phrase or words. Scoring is added up following the participant's recall of the story, and the higher the score, the better the memory performance of the participant.

Exercise Protocol

Those randomized to the exercise group were asked to walk on a treadmill for 15 minutes at a self-selected "brisk walk" pace. Specifically, we instructed them to self-select a "brisk walking pace", as if they were late to class. Participants were asked to remember that they needed to maintain whatever speed they chose throughout the duration of the 15 minute exercise bout and were asked to walk at least 3 miles per hour. Polar heart rate monitors were used to monitor the heart rates of each participant during the duration of the exercise protocol.

Statistical Analysis

All statistical analyses will be computed in SPSS (v. 22). A one-way ANOVA will be utilized to evaluate whether there were any statistically significant differences in memory function across the 4 groups. Statistical significance will be established as a nominal alpha of 0.05.

CHAPTER 4: RESULTS

Characteristics of the study participants are shown below in Table 1.

Table 1: Demographics

Variable	Point Estimate	Standard Deviation
Mean Age, yrs	21.0	1.3
% Female	61.3%	
Mean BMI, kgm^2	26.0	5.0
% Right-handed	91%	
% of participants on medications that affect mood/emotion	7.5%	
% of participants diagnosed with ADD/ADHD	11.3%	
Average Physical Activity (Minutes/Week)	197.1	205.2

The physiological responses from the exercise bout are shown by group in Table 2 below.

Table 2: Physiological Responses from Each Group

Group	Resting Heart Rate	Heart Rate at Middle of Exercise (7.5 minutes)	Heart Rate at End of Exercise (15 minutes)	Heart Rate 2-minutes post-exercise	Mean Positive Affect	Mean Negative Affect	Treadmill Speed
Exercise + Learning	76.0 (12.9)	117.0 (17.5)	118.4 (16.7)	82.6 (16.2)	30.6 (6.8)	14.5 (4.2)	3.4 (0.3)
Learning Only	76.9 (13.9)	-	-	-	28.9 (6.5)	14.7 (4.6)	-
Exercise Only	74.7 (14.9)	119.0 (18.8)	119.1 (18.4)	85.7 (16.2)	28.1 (7.0)	11.7 (3.1)	3.3 (0.2)
No Exercise + No Learning (control)	75.5 (11.0)	-	-	-	29.9 (7.2)	14.9 (7.9)	-

The memory scores for each group are shown below in Table 3.

Table 3: Memory Scores

Group	Immediate A	Delayed A	Immediate B	Delayed B	Gains A	Losses A	Gains B	Losses B
Exercise + Learning (E+L)	19.2 (3.9)	18.6 (3.8)	18.9 (3.6)	18.9 (3.6)	6.3 (10.8)	5.7 (7.6)	16.9 (20.2)	4.8 (4.2)
Learning Only (L)	17.1 (5.2)	16.7 (5.2)	18.2 (3.9)	18.1 (3.2)	12.9 (13.3)	7.1 (9.4)	15.6 (17.7)	5.7 (6.8)
Exercise Only (E)	12.7 (4.2)	12.5 (4.5)	14.2 (4.4)	14.1 (4.2)	10.3 (9.8)	9.8 (8.6)	9.6 (13.0)	7.6 (6.4)
Control Group (C)	12.4 (5.6)	11.9 (5.2)	13.3 (4.6)	13.3 (4.3)	5.9 (9.4)	8.3 (8.4)	9.6 (9.7)	8.4 (8.8)

Short-Term Memory (STM) Results

There was a statistically significant group difference for STM-A ($F=9.6$, $P<0.001$), with Ex+L, L, E, and C, respectively, having a higher to lower STM-A score. That is, for these respective groups, the STM-A scores were 19.2, 17.1, 12.7, and 12.4 (Figure 1). Ex+L was not statistically significantly different from L ($P=0.14$), but was from E ($P<0.001$) and C ($P<0.001$). Group L was significantly different from E ($P=0.006$) and C ($P=0.01$). Lastly, Group E was not significantly different from C ($P=0.82$).

There was a statistically significant group difference for STM-B ($F=8.9$, $P<0.001$), with Ex+L, L, E, and C, respectively, having a higher to lower STM-B score. That is, for these respective groups, the STM-B scores were 18.9, 18.2, 14.2, and 13.3. Ex+L was not statistically significantly different from L ($P=0.55$), but was from E ($P<0.001$) and C ($P<0.001$). Group L was significantly different from E ($P=0.005$) and C ($P=0.001$). Lastly, Group E was not significantly different from C ($P=0.53$).

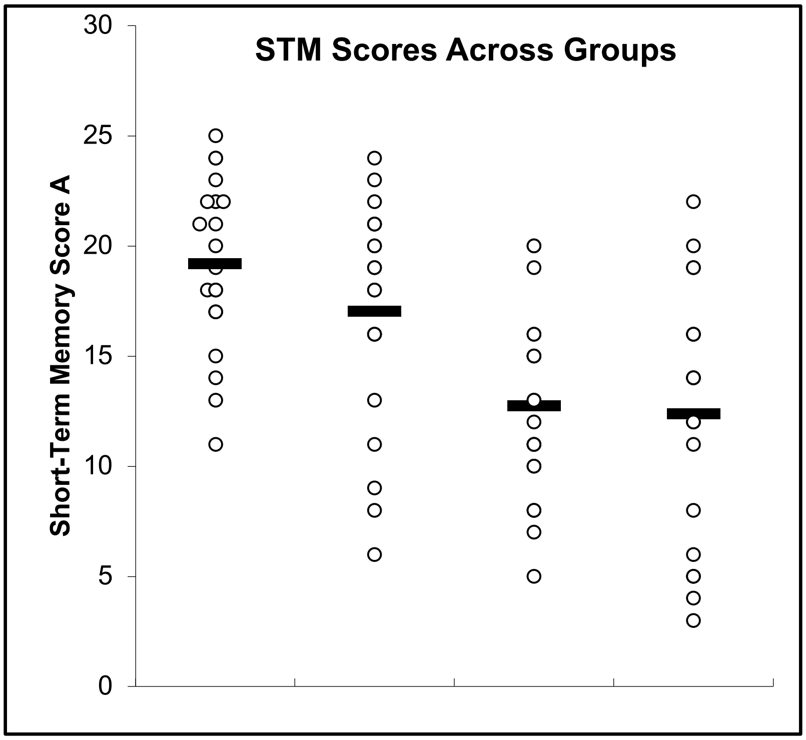

Figure 1: The distribution of scores for each participant's short-term memory test are documented above with averages being marked with a bar.

Long-Term Memory (LTM) Results

There was a statistically significant group difference for LTM-A (F=9.4, P<0.001), with Ex+L, L, E, and C, respectively, having a higher to lower LTM-A score. That is, for these respective groups, the LTM-A scores were 18.6, 16.7, 12.5, and 11.9 (Figure 2). Ex+L was not statistically significantly different from L (P=0.22), but was from E (P<0.001) and C (P<0.001). Group L was significantly different from E (P=0.009) and C (P=0.005). Lastly, Group E was not significantly different from C (P=0.69).

There was also a statistically significant group difference for LTM-B (F=10.4, P<0.001), with Ex+L, L, E, and C, respectively, having a higher to lower LTM-B score. That is, for these respective groups, the LTM-B scores were 18.9, 18.1, 14.1, and 13.3.

Ex+L was not statistically significantly different from L (P=0.43), but was from E (P<0.001) and C (P<0.001). Group L was significantly different from E (P=0.002) and C (P=0.004). Lastly, Group E was not significantly different from C (P=0.55).

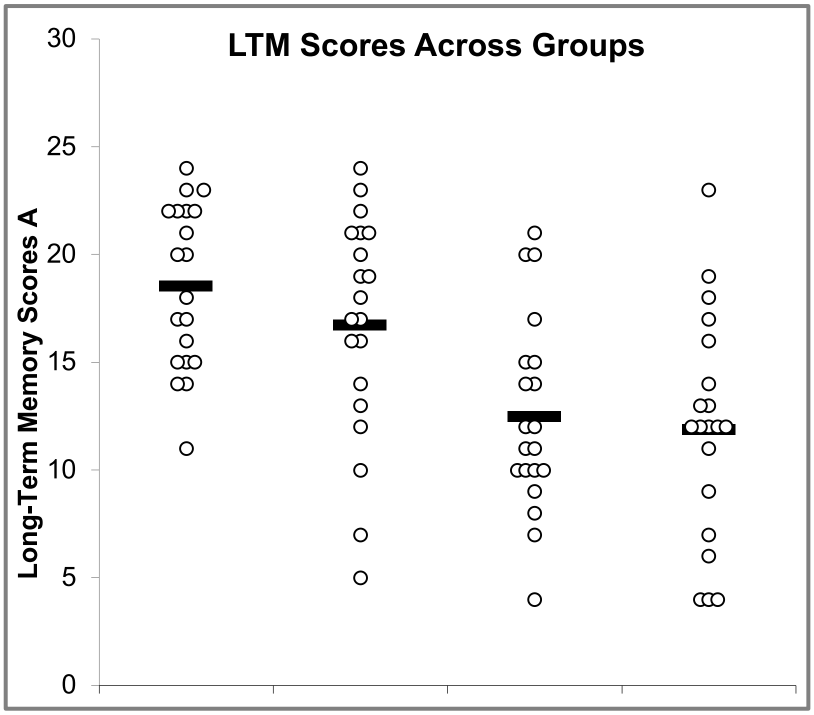

Figure 2: The LTM Scores for Story A are shown above for each participant, and the averages for each group are marked with a bar.

Perceptions of Exercise and the Learning Strategy

Among the participants who implemented the 3-R technique, they were asked whether they thought the technique was easy for them to implement. This included response options of strongly disagree (1), disagree (2), neutral (3), agree (4) and strongly agree (5). The mean (SD) score was 4.23 (0.86), suggesting that participants who were randomized into the groups that implemented this technique "agreed" that this technique was easy to implement.

These participants were also asked if they felt that this learning technique was useful in helping them remember the content. The mean (SD) for this question was 4.25 (0.70), suggesting that participants “agreed” that this technique helped them remember the content.

Lastly, among those randomized into a group involving the acute bout of exercise, they were asked if they felt that the exercise bout was useful in helping them remember the content. The mean (SD) for this question was 3.76 (0.83), suggesting that participants were just under the “agree” threshold regarding their perception that acute exercise helped them remember the content.

CHAPTER 5: DISCUSSION

Previous studies show that exercise and the use of learning strategies both have a beneficial impact on memory performance individually, but to our knowledge, there are no studies looking at the combined effects of cognitive training using a learning strategy and acute exercise in young-to-middle-aged adults. The purpose of this study was to look at the combined effects of cognitive and physical training to see if there was an additive, null, or deleterious effect on memory performance. Results showed that those in the exercise and learning group had significantly better memory scores than those in the exercise only and control groups. There were no statistically significant differences among those in the learning only group when compared to the exercise plus learning group; however, the latter group had a higher mean score for each of the memory outcomes.

Potential mechanisms for this could be long-term potentiation, which is the repeated firing of certain neuronal synapses that causes a strengthened memory. Both exercise and the learning strategy may induce LTP, therefore causing an additive effect on memory performance. Along with LTP, there may also be a potential associativity effect because the acute bout of exercise and learning strategy implementation are occurring around the same time. Associativity is observed when the weak input of the learning stimulus is completed shortly after the strong input of the acute exercise.

In a review paper by Laurenroth *et al.*, they looked at several studies for similar information about the combined effects of exercise and cognitive training on memory, but their approach was not identical to ours. Instead of employing an intensive cognitive training regimen, our study used a simpler, acute learning strategy immediately following exercise. In this review paper, however, they demonstrated that when exercise was coupled with cognitive training, cognition was enhanced when compared to those who only exercise or only engaged in cognitive training. Our findings align with these, as we demonstrated an additive effect of acute exercise and learning strategy implementation on memory function.

There are several potential implications stemming from the results of our study. One is that it may be beneficial to exercise prior to learning or encoding information. Even just an acute bout of exercise may stimulate LTP and boost memory function. Second, using the 3-R technique and being exposed to the information more than once can also improve memory function, so implementing this into a study routine may help one to better remember information for future testing. Finally, combining acute bouts of exercise and using the 3R technique may have even greater impacts on memory performance and function. Like all other studies, there are limitations of this study and its results. Our findings may not be generalizable to other populations, given that our sample consisted of only young, healthy adults. Future work should evaluate this paradigm among other populations and evaluate additional learning techniques, as well as other exercise intensity levels. A notable strength of this study is the experimental design and the study's novelty.

In conclusion, the results of this experiment demonstrate that memory function was enhanced, to the greatest extent, among those who engaged in an acute bout of exercise (brisk walking) and also implemented the 3-R learning technique, when compared to those who only exercised, only implemented the learning technique, or those doing neither. Further, participants, on average, perceived that acute exercise as well as the implemented learning technique, was useful in facilitating memory recall. Additionally, participants perceived the 3-R technique to be easy to implement.

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Appendix A

Table 1. Logical Memory Test Stories and Scoring

Line	Criteria for scoring	Score	
Logical Memory Story A			
1. Maria	*Maria* or a variation of	0	1
2. Anderson	*Anderson* required	0	1
3. was a law student	Indication of law student/scholar	0	1
4. at Otago University.	*Otago University* or *University of Dunedin*	0	1
5. She and her two friends	Indication *two other people* joined her	0	1
6. Anna and	*Anna* or variation of name	0	1
7. Michael	*Michael* or variation of name	0	1
8. went skiing	Indication of any snow sport	0	1
9. in Queenstown	*Queenstown* required	0	1
10. over the winter holidays.	Mention of vacation in cold season	0	1
11. They arrived in the afternoon,	Indication of arriving in the afternoon	0	1
12. checked into their hotel,	Indication of arriving at hotel	0	1
13. and went out for dinner.	Indication of going out for meal that night	0	1
14. This night	Indication the situation occurred night of arrival	0	1
15. Maria fell ill	Indication of being sick	0	1
16. with fever,	Indication of abnormally high body temperature	0	1
17. nausea,	Indication of any type of nausea	0	1
18. headache,	Indication of pain or ache in the head	0	1
19. and stomach cramps.	Indication of cramps or pain in the stomach	0	1
20. The doctor advised her	Indication of medical attention/advice	0	1
21. to stay in bed	Indication of advice to remain in bed	0	1
22. for two days	*Two days* required	0	1
23. and to drink tea.	Indication of drinking tea	0	1
24. Maria recovered quickly	Indication of a quick recovery	0	1
25. enjoying the rest of her holiday.	Indication of continuing holiday successfully	0	1
Logical Memory Story B			
1. Amanda	*Amanda* or variation of name	0	1
2. Wright	*Wright* required	0	1
3. was driving	Indication of driving	0	1
4. to the supermarket in her	Indication of store for destination	0	1
5. blue	*Blue* required	0	1
6. Toyota	*Toyota* reqiured	0	1
7. along Church Road,	*Church Road* or *Street* required	0	1
8. when she saw	Indication of seeing	0	1
9. a white	*White* required	0	1
10. limousine.	Indication of stretch/long vehicle	0	1
11. She was excited	Indication of aroused emotional state	0	1
12. thinking this may be a celebrity's car	Indication of famous person	0	1
13. visiting her town	Indication of visiting temporarily	0	1
14. for a concert.	Indication of performing	0	1
15. She slower down	Indication of slowing down her car	0	1
16. and tried to get a closer look.	Indication of trying to see famous person	0	1
17. Just then	Indication of a second event at the same time	0	1
18. her two	*Two* required	0	1
19. young	Indication of youth	0	1
20. children,	Indication of children	0	1
21. sitting in their back seats,	Indication of back seat/back of car	0	1
22. started quarrelling.	Indication of argument or being loud	0	1
23. She told them	Indication she spoke to her children	0	1
24. to be quiet,	Indication she asked them to behave	0	1
25. and continued her trip.	Indication she continued the trip	0	1

Appendix B

The Effects of Acute Exercise and Learning Strategy Implementation on Episodic Memory Performance

<u>*E-mail to Professor:*</u>

Dear Professor ___________:

We are conducting a research study evaluating the effects of exercise on memory function. Would you allow me to come into your class to provide a brief announcement of our study to help facilitate participant recruitment? If so, would you also be interested in offering extra credit to the students of yours who are willing to participate in our study? Per IRB policies, if indeed you are willing to provide extra credit, the IRB requires that alternative assignments (to earn extra credit) of comparable time and effort be made available to students who do not wish to participate in the research study.

Thank you for considering these requests. I look forward to hearing from you.

Sincerely,

Faith Harris
Department of Health, Exercise Science, and Recreation Management
The University of Mississippi

Paul Loprinzi, PhD
Department of Health, Exercise Science and Recreation Management
The University of Mississippi
662-915-5561
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<u>*Class Announcement:*</u>

"You are invited to participate in a research study evaluating the effects of exercise on memory capacity. This study is for individuals who are either physically active or sedentary. If you are interested in participating, we will ask that you arrive to the Exercise Psychology Lab for a single visit. During this visit, you will participate in a memory task that involves reading two passages and attempting to recall content from these passages. You also may be asked to walk on a treadmill for 15 minutes prior to the memory task.

We ask that you please refrain from taking marijuana or illegal drugs 48 hours prior to your visit, do not exercise 5 hours before, or have caffeine three hours before your visit. Also, please do not volunteer for this study if you are pregnant, current smoker or have had a concussion in the past 30 days.

I am going to pass out a sign-up sheet. If you are interested in participating, please write down your contact information and I will then contact you. Your professor may, or may not, be offering extra credit for your participation in our study. Your professor will discuss this with you. Thank you for considering participating in our study."

Word of Mouth:

"You are invited to participate in a research study evaluating the effects of exercise on working memory capacity. This study is for individuals who are either physically active or sedentary. If you are interested in participating, we will ask that you arrive to the Exercise Psychology Lab for a single visit. During this visit, you will participate in a memory task that involves reading two passages and attempting to recall content from these passages. You also may be asked to walk on a treadmill for 15 minutes prior to the memory task.

We ask that you please refrain from taking marijuana or illegal drugs 48 hours prior to your visit, do not exercise 5 hours before, or have caffeine three hours before your visit. Also, please do not volunteer for this study if you are pregnant, current smoker or have had a concussion in the past 30 days. Thank you for your time and consideration."

Appendix C

Consent to Participate in Research

Study Title: The Effects of Acute Exercise and Learning Strategy Implementation on Logic Memory Performance

Principal Investigator

Paul D. Loprinzi, Ph.D., Faculty
Department of Health, Exercise Science and Recreation Management

229 Turner Center

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(662) 915-5561

pdloprin@olemiss.edu

The University of Mississippi Institutional Review Board

Protocol # 18-007
Approval Date 08-11-17
Expiration date 08-10-18
Signature

☐ By checking this box, I certify that I am 18 years of age or older.

The purpose of this study

This is a research study for students, alumni, faculty, and staff at the University of Mississippi. The purpose of this study is to see if acute exercise can improve memory function.

What you will do for this study

If you agree to participate and thus provide voluntary consent, you will complete 1 laboratory visit. During this visit, you will participate in a memory task that involves reading two passages and attempting to recall content from these passages. You also may be asked to walk on a treadmill for 15 minutes prior to the memory task.

Time required for this study

The laboratory visit will likely last up to 60 minutes.

Possible risks from your participation

There is a possibility that you could fall off the treadmill. However, you will be able to hold onto the handrails at any time.

Benefits from your participation

This study will not benefit you directly, but findings from this study will improve our understanding of the relationship between exercise intensity and working memory capacity.

Confidentiality

Members of the research team will have access to your records. We will protect confidentiality by physically separating information that identifies you from your responses – which is more secure than the way medical records must be stored.

Members of the Institutional Review Board (IRB) – the committee responsible for reviewing the ethics of, approving, and monitoring all research with humans – has authority to access all records. However, the IRB will request identifiers only in special cases.

We will not release identifiable results of the study to anyone else without your written consent unless required by law.

Right to Withdraw

You do not have to volunteer for this study, and there is no penalty if you refuse. If you start the study and decide that you do not want to finish, just email the experimenter. Whether you participate or withdraw, your decision will not affect your current or future relationship with the Department of Health, Exercise Science and Recreation Management, or with the University, and it will not cause you to lose any benefits to which you are entitled.

Student Participants in Investigators' Classes

Special human research subject protections apply where there is any possibility of coercion – such as for students in classes of investigators. Investigators can recruit from their classes but only by providing information on availability of studies. They can encourage you to participate, but they cannot exert any coercive pressure for you to do so. Therefore, if you experience any coercion from your instructor, you should contact the IRB via phone (662-915-7482) or email (irb@olemiss.edu) and report the specific form of coercion. You will remain anonymous in an investigation.

IRB Approval

This study has been reviewed by The University of Mississippi's Institutional Review Board (IRB). The IRB has determined that this study fulfills the human research subject protections obligations required by state and federal law and University policies. If you have any questions, concerns, or reports regarding your rights as a participant of research, please contact the IRB at (662) 915-7482.

Please ask the researcher if there is anything that is not clear or if you need more information. When all your questions have been answered, you can decide if you want to be in the study or not.

Statement of Consent

I have read the above information. I have been given a copy of this form. I have had an opportunity to ask questions, and I have received answers. I consent to participate in the study.
Furthermore, I also affirm that the experimenter explained the study to me and told me about the study's risks as well as my right to refuse to participate and to withdraw.

Signature of Participant

Date

Printed name of Participant

NOTE TO PARTICIPANTS: DO NOT SIGN THIS FORM

IF THE IRB APPROVAL STAMP ON THE FIRST PAGE HAS EXPIRED