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Physical activity is beneficial to cognitive function, including memory which is an essential function we use in our daily life. Roig, Nordbrandt, Geertsen, and Nielsen (2013) meta-analysis provides evidence that a single bout of exercise has positive effects on short-term/working and long-term memory. Additionally, the majority of studies showed that compared to a no-treatment control condition, improved memory task performance was reported when an acute bout of exercise occurred prior to memory tasks. However, only two studies have specifically investigated the influence of exercise timing relative to exposure to the memory task on memory performance (Labban & Etnier, 2011; Salas, Minakata, & Kelemen, 2011). In order to expand the literature, the current study examined the effects of the timing of exercise relative to a memory task on long-term recall performance by assigning participants into one of four experimental conditions: 1) exercise before memory exposure, 2) exercise after memory exposure, 3) exercise before long-term recall, and 4) no-exercise control condition. Eight-three participants completed the study. Results showed that no differences among treatment groups reached statistical significance on all memory measures. These findings indicated that a single, short bout of exercise at different points relative to memory exposure neither benefit nor hinder memory task performance. Future research exploring how exercise intensity and duration interact to influence memory performance is needed.

EXPLORING THE INFLUENCE OF EXERCISE TIMING RELATIVE TO

EXPOSURE TO A MEMORY TASK ON LONG-TERM RECALL

by

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CHAPTER I

INTRODUCTION

It is well known that physical activity has positive effects on our body and mind. The literature exploring physical activity benefits for cognition is growing rapidly. Meta-analytic reviews provide evidence that both chronic physical activity and a single bout of exercise improve cognitive performance (Chang, Labban, Gapin, & Etnier, 2012; Colcombe & Kramer, 2003; Etnier, Nowell, Landers, & Sibley, 2006; Etnier et al., 1997; Lambourne & Tomporowski, 2010; Sibley & Etnier, 2003; Smith et al., 2010; Sofi et al., 2011).

As part of cognitive function, memory plays a vital role in daily living. There are several types of memory, and working memory, short-term memory, and long-term memory are the most widely studied memory types in the physical activity literature. From an information processing perspective, there are three main processes required for memory formation: encoding, storage, and retrival. Sensory inputs (e.g., visual and audio stimuli) need to be encoded into short-term memory so the brain system can further process the information. This information can be stored for a brief duration in short-term memory (less than a minute) or a prolonged duration in long-term memory (from a few minutes to a lifetime). Attention is required in these processes. Stored information can be retrieved from short-term and long-term memory when necessary. The main difference between long-term and short-term memory is that long-term memory requires a relatively long-term stablization and consolidation for retrieval in the future.

Roig et al. (2013) utilized meta-analytic techniques to summarize the effects of cardiovascular exercise on memory. Twenty-two studies using an acute exercise paradigm were included in this meta-analysis. After removing one study that was designed to test the detrimental effect of prolonged exercise on cognitive performance, Roig and colleagues found that acute cardiovascular exercise has a small effect (SMD=0.26) on short-term/working memory. They also reported that acute cardiovascular exercise has a moderate effect (SMD=0.52) on long-term memory. In addition, empirical studies generally support that a single bout of exercise benefits memory performance. Compared to no-exercise control conditions or pre-exercise baseline, several studies have shown improved memory performance in response to an acute bout of exercise prior to a memory task in laboratory (Coles & Tomporowski, 2008; Winter et al., 2007) and school settings (Etnier, Labban, Piepmeier, Davis, & Henning, 2014; Pesce, Crova, Cereatti, Casella, & Bellucci, 2009).

Although evidence supports that a single bout of exercise prior to exposure to a memory task facilitates memory performance, research exploring the influence of the specific exercise timing relative to the memory task is limited. Only two studies have directly examined this research question by manipulating the timing of acute exercise relative to memory stimuli exposure. Labban and Etnier (2011) randomly assigned healthy young adults to either exercise-prior, exercise-after, or no-exercise control condition to test the influence of exposure timing to the to-be remembered information relative to the acute exercise bout. The exercise bout lasted for 30 minutes on a cycle ergometer and included a 5-minute warm-up, 20-minute moderate intensity exercise, and 5-minute cool-down. The standard New York University Paragraphs for immediate and delayed recall were used to assess memory performance. In this task, participants heard one story then were asked to recall the story as close to the original as possible. Then, the same procedure was repeated again for another story two times. The Stroop task was administered as a distractor to prevent rehearsal between the memory task and delayed recall. After a 35-minute delay period, the authors found that participants recalled more paragraph elements only in the exercise-prior condition than the control condition. Therefore, the authors concluded that the beneficial effects of acute exercise occur in early stages of memory formation.

Similar findings were reported by Salas et al. (2011). The authors used a 2 by 2 factorial design. Based on whether they were to exercise or rest before encoding and before immediate recall, young adults were randomly assigned to walking-sitting, walking-walking, sitting-sitting, or sitting-walking conditions. Participants walked for 10 minutes at a brisk pace in the walking condition whereas participants viewed a 10-minute slide show of neutral landscape pictures while sitting. For the memory task, concrete nouns were presented on a screen by a digital projector at the encoding phase and participants needed to recall as many as they could remember at the retrieval phase. Results showed that there was a significant positive effect on encoding. That is, participants who walked before encoding recalled more items than participants who sat before encoding. No other significant effects were found. Hence, the authors concluded that the exercise-induced memory advantage only occurs when the bout of exercise precedes the encoding phase but does not have a positive effect on the retrieval phase.

In summary, empirical studies have shown that a single bout of exercise before memory stimuli exposure benefits later memory task performance. However, research exploring the timing of acute exercise relative to the memory task is very limited. Only two studies have directly manipulated the timing of exercise with respect to exposure to the memory task (Labban & Etnier, 2011; Salas et al., 2011), with only one of these examining if acute exercise before long-term recall benefits performance (Salas et al., 2011). The purpose of the current study was to add to the extant literature by investigating the effects of timing of exercise relative to memory task on long-term recall performance. This study extend our understanding by comparing three different exercise timing conditions (i.e., before memory exposure, after memory exposure, and before long-term recall) to no-exercise control condition, using children as participants, and by using a verbal memory task. Based on the previous findings, we hypothesized that all acute exercise conditions benefits memory performance compared to the no-exercise control condition. In addition, participants in the exercise before memory exposure condition perform better than the other two exercise conditions.

CHAPTER II

LITERATURE REVIEW

Memory is not simply the ability to remember events we have experienced, but it is also the ability to generalize knowledge to new situations and to use it to make inferences about the world in which we live. Memory is a complex construct and can be categorized into different types. The most commonly studied types in the physical acitivy literature are short-term memory, working memory, and long-term memory. Short-term memory and working memory are similar but distinct concepts. They both require attention until the target information is needed for recall. However, working memory is different from short-term memory because it is not simply a temporary storage of information, but rather has features such as updating and manipulation of information (Baddeley, 2003). The most distinct differences between short-term memory and long-term memory are with regards to their duration and capacity (Cowan, 2008). Specifically, compared to long-term memory, information in short-term memory decays over time. In addition, the number of items that can be held in short-term memory is limited.

In the past few decades, the empirical literature on physical activity and cognition has been accumulating rapidly. Evidence has shown that physical activity benefits cognition with meta-analytic reviews reporting positive effects from both acute exercise and chronic physical activity on cognitive function (Chang et al., 2012; Colcombe &

Kramer, 2003; Etnier et al., 2006; Etnier et al., 1997; Lambourne & Tomporowski, 2010; Sibley & Etnier, 2003; Smith et al., 2010; Sofi et al., 2011). One line of research has focused on examining the effects of acute exercise on memory. Roig et al. (2013) conducted a meta-analysis specifically focused on the effects of cardiovascular exercise on memory. The authors included 22 studies which examined the effects of acute cardiovascular exercise on memory and reported positive effect sizes. Specifically, acute cardiovascular exercise was found to have a small positive effect (SMD=0.26) on short-term and working memory, after removing one study that was designed to test the detrimental effect of prolonged exercise on cognitive performance. In addition, acute cardiovascular exercise also has a moderate effect (SMD=0.52) on long-term memory. Although meta-analytic techniques can be used to statistically summarize findings from different studies, interpretation of these results should be made with caution. The reason is that the findings from meta-analyses represent averages across studies with a variety of designs, tasks, protocols, and populations; therefore, it is also important to understand the context of each of the individual studies.

Martins, Kavussanu, Willoughby, and Ring (2013) provide an example of a study exploring the effects of acute exercise on working memory performance during exercise. In their first experiment, participants were randomly assigned to either the exercise group or control group. For the exercise group, participants complete the Paced Auditory Serial Addition Task (PASAT), a working memory task, while cycling at moderate intensity. As for the control group, participants completed the PASAT while sitting at rest on a cycle ergometer. Results showed that the exercise group outperformed the control group after the first trial block. In their second experiment, the authors used the Sternberg task to further investigate the effects of acute exercise on working memory. Participants first performed the Sternberg task while sitting on a cycle ergometer as a control condition. Then, participants performed the task again at one of three randomly assigned intensity levels (very low, low, and medium). Results showed that participants in the low and medium, but not the very low exercise intensity, groups performed significantly better than the control group. Therefore, the authors concluded that working memory performance can be facilitated by an acute bout of moderate intensity aerobic exercise.

Other researchers have examined the effects of exercise on working memory performance after a single bout of exercise. Pontifex, Hillman, Fernhall, Thompson, and Valentini (2009) provided evidence that acute aerobic exercise benefits working memory. A modified Sternberg task was used to assess working memory in this study. Participants completed the working memory task at three different points: before the start of, immediately after, and 30 minutes after a treatment condition. Participants completed three treatment conditions in a counterbalanced order on separate days. The treatment conditions consisted of 30 minutes of aerobic exercise, 30 minutes of resistance exercise, and 30 minutes of rest on a seat. Results showed better performance on the Sternberg task immediately and 30 minutes after treatment relative to before treatment only in the aerobic exercise condition. Therefore, the authors concluded that beneficial effects on memory induced by acute exercise are specific to aerobic exercise.

Other researchers have used both behavioral and neuroimaging measures to further understand the overt and covert effects of acute exercise on working memory. Li et al. (2014) reported increased brain activation in response to exercise in regions including prefrontal cortex, a brain structure which is highly associated with working memory. Fifteen young females performed the N-back task after a 20-minute bout of moderate exercise and after the same period of rest presented in a counterbalanced order. Functional magnetic resonance imaging (fMRI) was used to assess brain activation during the N-back task. In the N-back task, a sequence of stimuli were presented and participants were asked to identify whether the current stimulus matched the stimulus from N steps earlier in the sequence. For example, in the 2-back condition, participants needed to judge whether the current stimulus was the same as the stimulus two positions before it. Although there was no significant difference between the two treatment conditions in behavioral performance, elevated brain activation in regions including the right middle prefrontal gyrus, the right lingual gyrus, and the left fusiform gyrus as well as decreased activation in the anterior cingulate cortexes, the left inferior frontal gyrus, and the right paracentral lobule were found under the 2-back condition after acute moderate exercise. Based on these findings, the authors suggested that a single bout of moderate exercise could benefit working memory at a neural level.

To understand differential effects of acute exercise on short-term and long-term memory, several studies included both short-term and long-term memory measures in the same study. Coles and Tomporowski (2008) observed better performance on long-term memory after a single bout of exercise compared to control conditions. In this study, participants went through three experimental conditions in a counterbalanced order: 1) moderate aerobic exercise on a cycle ergometer for 40 minutes; 2) sitting on a cycle ergometer for 40 minutes; and 3) sitting on a chair for 40 minutes. Two memory tasks were administered before and after experimental conditions to assess memory. Specifically, the Brown-Peterson test was used to measure short-term memory. In this test, participants were asked to remember 20 trigrams (e.g., “KYZ”), each was presented for two seconds. After varied delays (i.e., 3, 9, or 18 seconds), participants were asked to recall the memory set. Another free recall task was used to assess long-term memory. In this task, participants were asked to remember a 40-item word list, each word was presented for five seconds. Immediate and delayed recall were assessed after a 100-second consolidation period and 12 minutes after the word list presentation. Results showed that a single bout of 40-minutes of aerobic exercise did not influence performance on the Brown-Peterson test. In addition, analysis of data for the free recall task revealed significant declines on items recalled post-intervention compared to pre-intervention across the three experimental conditions. However, for the delayed recall, the authors found that performance on the primacy and recency portions of the word list was decreased in the two control conditions but maintained in the exercise condition. Therefore, the authors suggested that a single bout of moderate aerobic exercise may facilitate consolidation of information into long-term memory.

Pesce et al. (2009) suggested that submaximal exercise performed during physical education class may facilitate memory storage. In this study, students went through three experimental sessions. The first session was designed to assess students’ baseline memory performance. In the memory task, a 20-item word listed was presented one word at a time for 5 seconds each. After 100 seconds given as consolidation period, students were asked to write down as many words as possible regardless of the order of presentation (immediate free recall). Another free recall was administered 12 minutes later (delayed free recall). In the other two sessions, students performed the memory task after an hour of a physical education class which consisted of either team games or circuit training but at a similar intensity (moderate to vigorous). Results showed that compared to baseline performance, students significantly recalled more items from both primacy (i.e., the first 5 words) and recency (i.e., the last 5 words) portions of the list for immediate free recall after team games. As for delayed free recall, students only significantly recalled more items from the recency portion of the list after both team games and aerobic training. Based on these findings, the authors concluded that acute exercise may benefit memory storage.

More recently, Etnier et al. (2014) conducted a study in a school setting and showed that an acute bout of exercise in physical education class could benefit students' verbal learning and long-term memory. In this study, 6^{th} graders (n=43) were randomly assigned to an exercise condition or a non-treatment control condition. In the exercise condition, participants performed the Progressive Aerobic Cardiovascular Endurance Test (PACER), which is a part of the FITNESSGRAM, as a measure of aerobic capacity. In the PACER, participants need to cover 20 meters at an increasingly quicker pace with one audio tone informing them when to start running and the other audio tone indicating when they should have finished the run. Therefore, participants perform at a submaximal level for most of the PACER and at a maximal level in the final stage. In the non-treatment control condition, students performed the memory task in the beginning of their physical education class before any exercise. The Rey Auditory Verbal Learning Test (RAVLT) was used to assess verbal learning and memory. In the RAVLT, participants hear a list of 15 words and then are asked to write down as many words they can remember as possible. This process repeats 5 times. The first trial is considered as a measure of short-term memory and the gain in performance over the next 4 trials is considered a measure of verbal learning. Then a different word list is played as an interference trial which prevents participants from rehearsing words from the original word list. After participants write down the words they remember from the second word list, they are asked to recall the words from the original word list as a measure of long-term memory (brief-delayed recall). Another measure of long-term memory was assessed 24-hr later with a recognition task which is a 50-word list (15 from the original list, 15 from the second list, and 20 new words) and participants need to identify whether the word was from the original list, the second list, or neither. Results showed that participants in the exercise condition recalled more words than participants in the non-treatment control condition after the 3rd, 4th, and 5th exposure to the original word list, indicating a single bout of exercise may facilitate verbal learning. In addition, participants in the exercise condition performed significantly better at the brief-delayed recall than participants in the non-treatment control condition, suggesting acute exercise provides benefits for long-term memory.

A growing body of literature has been aimed at understanding potential mechanisms of the relation between acute exercise and memory. Brain-derived neurotrophic factor (BDNF) is one of the most focused upon candidates. Winter et al.

(2007) conducted a study to understand the effects of acute exercise on learning and memory. In addition, the authors also assessed participants' BDNF levels before and after acute exercise to see if changes in BDNF level link to task performance. Participants completed three experimental conditions in a randomized order. The conditions consisted of a 15-minute rest (control condition), a 40-minute bout of steady-state running (moderate condition), and two 3-minute bouts of sprinting at an increasing speed (intense condition). After the treatment, participants were asked to learn 600 novel word-picture associations (e.g., /glump/ and car). Immediate retention, short-delayed retention, and long-delayed retention tests were assessed immediately, 1 week, and 8 month after the learning phase, respectively. Blood samples were obtained before and after the treatment as well as after the learning phase. Results showed that task performance (rate of learning) was significantly better following the intense condition compared to control and moderate conditions. Importantly, more sustained BDNF levels in the intense condition were related to better short-term learning. Based on these finding, the authors concluded that BDNF may be a mediator that explains why acute intense exercise improves learning.

Similarly, Griffin et al. (2011) found that a VO_{2Max} test on a cycle ergometer benefits performance on a face-name matching task. Importantly, this effect was paralleled by an increased concentration of BDNF. The authors investigated the effects of acute exercise on cognition in healthy, sedentary young adults. Additionally, the authors also examined the role of neurotrophic factors (i.e., BDNF and insulin-like growth factor, IGF-1) in exercise-induced cognitive changes. Participants were randomly assigned to either an exercise condition, where they completed a graded exercise test to obtain their VO_{2Max}, or a control condition, where they rested for 30 minutes. Participants completed a face-name matching task before and after treatment, where they were presented with 10 unfamiliar faces paired with names for 3.5 seconds each followed by a distractor task to prevent face-name associations rehearsal. After that, previously-viewed faces were presented, and participants were asked to recall the name paired with it. Blood samples were collected at the beginning of the experimental session right before the first face-name matching task (0-min), before treatment (30-min), after treatment (60-min), and after the second face-name matching task (90-min). Results showed that compared to a non-exercise control group, enhanced performance of the face-name matching task was observed in the exercise group. In addition, BDNF concentration was significantly higher after exercise (60-min) relative to baseline (0-min) and before exercise (30-min), but showed no difference with the last blood draw (90-min). Therefore, the authors suggested that BDNF may be a mediator of acute exercise-induced cognitive enhancement.

Despite that researchers have suggested that acute exercise benefits particular processes in memory formation (Coles & Tomporowski, 2008), only two studies have directly examined this hypothesis by manipulating the timing of acute exercise relative to memory stimuli exposure. From an information processing perspective, the formation of a memory consists of several processes including encoding, retention, consolidation, and subsequent retrieval of information when necessary. Cowan (1988) provided a comprehensive review of the human information system. Typically, stimuli from the outside world first enter in to sensory memory, where they can only be held for only several hundred milliseconds. If further processed, this information will pass along to short-term memory, which can hold information for 20-30 seconds. Some of this information is further processed and passed along to long-term memory. Information in long-term memory may last a lifetime. It should be noted that parts of information will not be processed, and therefore, will not be remembered. There are main stages for memory formation and retrieval. Encoding allows stimuli from the environment to be converted into mental representations that can be stored in the human brain as well as recalled from memory in the future. Consolidation helps memory stabilization, which includes two specific processes: synaptic consolidation and system consolidation. The former occurs within the first few hours after encoding and the latter occurs when hippocampus-dependent memories become independent of the hippocampus over a period of weeks to years. Storage is a relatively passive process of maintaining information in sensory memory, short-term memory, and long-term memory. Retrieval refers to the subsequent re-accessing of information encoded and stored in the brain.

Labban and Etnier (2011) conducted a study to investigate the influence of timing of exercise relative to memory exposure on long-term memory. In this study, healthy young adults were randomly assigned to one of the following three groups relative to exposure to a memory task: exercise-prior, exercise-after, or no-exercise. Acute exercise consisted of a 5-minute warm-up, 20-minutes of moderate intensity exercise, and a 5-minute cool-down on a cycle ergometer. For the long-term memory task, participants heard one story then were asked to immediately recall the story as close to the original as possible. Then, the same procedure was repeated again for another story two times. In order to prevent rehearsal, participants also completed the Stroop Task as a distractor at the end of this phase. Results showed that only participants in the exercise-prior group, but not in the exercise-after group, recalled significantly more paragraph elements than participants in the no-exercise control group. The authors suggested that acute exercise facilitates early stages of memory formation but not the later stages based on the finding that the beneficial effects of acute exercise on long-term memory only happened when acute exercise occurred prior to memory exposure.

Salas et al. (2011) conducted a study to investigate the effects of a short bout of aerobic exercise on memory performance. Eighty young adults were randomly assigned to one of 4 conditions using a 2 (encoding: walking vs. sitting) by 2 (retrieval: walking vs. sitting) factorial design. For the walking condition, participants were asked to walk for 10 minutes at a brisk pace, whereas for the sitting condition, participants viewed a 10-minute slide show consisting of neutral landscape pictures. Therefore, participants were either exercising before studying memory materials, exercising before recalling memory materials, exercising before both studying and recalling memory materials, or no exercise before studying and recalling memory materials. Memory performance was assessed by number of presented nouns participants could recall. Only the main effect of encoding reached significance. Participants who walked before encoding had higher recall than those who sat before encoding. No main effect of retrieval or interaction were found. Therefore, the authors concluded that a 10-minute walk before studying could lead to memory advantage.

In sum, the empirical literature generally supports that acute exercise benefits memory. However, most studies demonstrated that compared to control condition, improved memory task performance was reported if a single bout of exercise occurred prior to the memory task. Research exploring the timing of exercise relative to memory task is still in paucity. Only two studies manipulated the timing of exercise other than prior to memory task (Labban & Etnier, 2011; Salas et al., 2011). Therefore, research investigating the timing of exercise relative to memory task is needed to extend the current literature.

CHAPTER III

METHODS

Participants

Eight-three school-aged children (from 4^{th} grade to 8^{th} grade) were recruited from a local school in Greensboro, North Carolina. The University's Institutional Review Board (IRB) approved the study and consent and assent form were obtained from the participant's parent or guardian and from the participant, respectively. Participants' demographic information, age at time of entering the study, sexual maturity (i.e., Tanner score), and height and weight (to calculate body mass index, BMI) were collected from their parents or guardians.

Measures

Digit Span. Digit Span was used to assess participants' short-term and working memory at baseline. In the "Forward" condition, participants saw a pre-created slide of digits, one digit at a time, and then were asked to write down the digits they saw in the presented order. The length of sequences ranges from 3 to 7 and each length has two sequences. The procedure of the "Backward" condition is the same as the "Forward" condition except that participants were asked to write down the digits in the reverse order as they were presented. The "Forward" condition was considered a measure of short-term memory because participants only needed to hold the information in their mental space while the "Backward" condition was considered a measure of working memory because participants needed to manipulate the information they held in their mental space. An average score of memory span from the “Forward” and “Backward” conditions was calculated for each participant as baseline memory performance.

Rey Auditory Verbal Learning Test (RAVLT). The RAVLT was used to assess memory performance (Schmidt, 1996). Two pre-recorded 15-word lists (List A and List B) were used in the study so participants heard the lists of words read in exactly the same fashion. After hearing List A, participants were asked to write down as many words as they could remember in two minutes regardless of the spelling and the order of the words presented. This process was repeated five times (Trials 1 -5). For Trial 6, participants heard a different word list (List B) and then wrote down as many words as possible from List B regardless of the spelling and the order of the words presented. Following Trial 6 and without hearing List A again, participants were asked to write down as many words as possible from List A (Trial 7). Trial 1 was considered a measure of short-term memory (immediate recall). Gains in recall from Trial 1 to Trial 5 was considered as a measure of verbal learning. Trial 7 was considered as a measure of long-term memory (brief-delayed recall). Another long-term memory measure was administered on the next day and participants were asked to write down as many words as they could remember from list A (24-hr recall). Following 24-hr recall, participants were given a 50-item word list (i.e., 15 from List A, 15 from List B, and 20 new words) and asked to identify if the word was from List A, List B, or was a new word (24-hr recognition).

Heart Rate. Heart rate was measured by pulse palpation for a 15-second period on radius or carotid. Heart rate was measured immediately after participants finished the exercise.

Exercise Protocol

The mile run test, which is part of the FITNESSGRAM, was used for the exercise protocol in the present study. In this running test, participants were encouraged to run a mile in the shortest time possible. Participants had performed the mile run test several times during the school year as part of their physical education curriculum as a measure of aerobic fitness.

Procedure

The research team visited the school in order to introduce themselves and the study to the potential participants. IRB-approved consent and assent forms were sent home with participants in order for their parents or guardians to become aware of the study and to approve their child' participation. Signed informed consents and assents were returned to the research team before data collection.

Data collection took place on three days. On Day 1, participants performed the Digit Span Forward and Backward conditions to assess their short-term and working memory, respectively. On Day 2 and Day 3, participants were assigned to one of the following four groups matching for grade, sex, and Digit Span performance: 1) mile-run before memory test (i.e., Mile Run-RAVLT); 2) mile-run after memory test (i.e., RAVLT-Mile Run); 3) mile-run before recall (i.e., Mile Run-Recall); and 4) no-exercise control group (i.e., Control). When students arrived at class, they were informed as to which group they were assigned. Students assigned to the Mile Run-RAVLT group warmed-up by jogging approximately 100 m and stretching and then performed the mile run. Immediately after finishing their run, these students were escorted to a nearby testing location to perform the memory test. The time between completing the run and starting the memory task was controlled to be less than 5 min. Students assigned to the RAVLT-Mile Run group completed the memory test first and then performed the warm-up described above and their mile run. Students in the other two groups (i.e., Mile Run-Recall and Control groups) completed the memory task without performing the mile-run before or after it. Following the memory test, they participated in low intensity activities such as stretching, yoga, bowling, throwing and catching lacrosse ball or Frisbee for the remainder of their physical education class.

On Day 3, students assigned to the Mile Run-Recall group performed the same exercise protocol described above before they performed the memory recall. Students assigned to the other three groups performed their memory recall without any activity before it and then returned to their normal physical education activities. The study design and protocol are depicted in Figure 1.

Statistical Analysis

Participants' age, body mass index (BMI), sexual maturity (i.e., Tanner score), mile run time, heart rate, and performance on Digit Span are presented in Table 1. One-way analyses of variance (ANOVAs) were conducted to test for differences in these variables as a function of condition. Participants' performance on the RAVLT is presented in Table 2. To analyze exercise effects on short-term and long-term memory, performance on Trial 1, Trial 7, 24-hr recall, and recognition were tested using one-way ANOVAs. To analyze the effects on performance from Trial 1 to Trial 5, a mixed ANOVA was conducted to test for differences in learning as a function of trial (withinsubjects variable) and the between-subjects factor of condition. If the assumption of sphericity was violated, a Huynh-Feldt correction was applied. In the event of significant effects, partial eta squared is presented as a measure of effect sizes and, when appropriate, Tukey post-hoc analyses were conducted.

CHAPTER IV

RESULTS

Regarding participants' demographic characteristics, a chi-square test showed that there was no significant difference in the proportion of boys to girls in the treatment conditions, χ^2 (4, n=84)=3.24, p=.54. In addition, one-way ANOVAs showed that there were no significant differences in participants' age, F(3,81)=0.36, p=.78, BMI, F(3,71)=0.48, p=.70, or Tanner score, F(3,75)=0.41, p=.75, as a function of condition. As for participants' baseline performance, one-way ANOVA showed that there was no significant difference in participants' Digit Span performance as a function of condition, F(3,82)=0.85, p=.47. With regard to participants' measures related to the exercise protocol, one-way ANOVAs showed that there was no significant difference in participants' mile run time, F(3,82)=0.27, p=.48, or heart rate, F(3,81)=0.98, p=.41, as a function of condition.

As for participants' performance on the RAVLT, no significant difference in short-term memory or long-term memory measures reached statistical significance, F(3,82)=0.64, p=.59, F(3,82)=1.13, p=.34, F(3,82)=1.17, p=.33, F(3,82)=0.60, p=.61 for Trial 1, Trial 7, 24-hr recall, and recognition test, respectively. Results of the mixed ANOVA revealed a main effect for trial, F(4, 76)=94.70, p<.001, partial η^2=0.83. Post-hoc analysis indicated that performance improved significantly from one trial to the next trial until performance plateaued at Trial 4 (Trial 1: M=5.99, SD=1.76; Trial 2: M=8.12, SD=2.32; Trial 3: M=9.86, SD=2.22; Trial 4: M=10.78, SD=2.34; Trial 5: M=11.00, SD=2.37), $p<.001$. None of the other effects was statistically significant, $p>.05$.

A few exploratory analyses were conducted in order to test potential moderators and covariates of the relation between treatment conditions and long-term memory performance. First of all, sex, grade, and Tanner score did not moderate the relationship between treatment conditions and long-term memory performance, ps>.05. In addition, mile run time and Digit Span performance were not correlated with long-term memory performance (*p*'s>.05), therefore, their potential role as covariates was ruled out.

Beyond the previously described exploratory analyses, effect size (i.e., Cohen' d) was calculated by comparing each exercise condition and the control condition for the 24-hr recall and recognition test (Figure 2). Compared to the control condition, Mile Run-RAVLT condition showed small to medium effect size on both 24-hr recall and recognition test, Cohen's d= 0.41 and 0.29, respectively. Effect sizes in other condition are trivial (Cohen's d < 0.2).

CHAPTER V

DISCUSSION

The current study aimed to extend our understanding of the influences of exercise timing relative to a memory task on performance on long-term memory. Participants were randomly assigned in a matched fashion to three different exercise conditions or a no-exercise control condition by matching their short-term/working memory performance, gender, and grade. Participants in exercise conditions either performed the Mile Run before memory exposure (i.e., Mile Run-RAVLT), after memory exposure (i.e., RAVLT-Mile Run), or before long-term recall on the next day (i.e., Mile Run-Recall). Results showed that no differences on memory measures reached statistical significance among treatment conditions. Several potential moderators and covariates including sex, grade, Tanner score, mile run time, and Digit Span performance were tested and ruled out by the exploratory analyses. However, it should be noted that compared to the no-exercise control condition, Mile Run-RAVLT condition showed small-to-medium effect size on both 24-hr recall and recognition test. The findings of the current study were not consistent with the meta-analysis conducted by Roig et al. (2013) and the majority of empirical studies (Etnier et al., 2014; Labban & Etnier, 2011; Pesce, 2012; Salas et al., 2011). Three possible explanations come to mind for these unexpected findings. The first relates to the duration of the exercise protocol. The second relates to the timing of long-term memory tested. The third relates to the issue of statistical power.

Relative to the duration of the exercise, the mile run was used as the exercise protocol in the current study. No significant differences were observed for participants' mile run time or heart rate among treatment conditions, which indicated participants in each condition went through the same exercise protocol. The overall average heart rate after their mile run was 177.39 beats per minute (BPM), which is more than 88% of their age-predicted maximal heart rate, indicating they performed the mile run at vigorous level. Importantly, the overall average time to complete the mile was about 8 minutes and 20 seconds. According to Chang et al. (2012) meta-analysis, exercise duration is an important moderator between acute exercise and cognitive function relation. Specifically, the authors reported that only exercise longer than 20 minutes results in positive effects. Similar conclusion was proposed by Brisswalter, Collardeau, and René (2002). Therefore, it is possible that participants finished their mile run in such a short duration may not be enough to produce the facilitating effects of exercise on memory performance.

The second reason that the findings of the current study were not consistent with the findings of Labban and Etnier (2011) and Salas et al. (2011) may be due to the timing of when long-term memory (i.e., recall) was measured. In Labban and Etnier (2011), participants either performed the recall approximately 30 minutes after or immediately after a single bout of exercise for exercise-prior and exercise-after groups, respectively. Similarly, participants in Salas et al. (2011) also performed the recall within 30 minutes (i.e., walking-sitting condition) or immediately after (walking-walking and sitting-walking conditions) they completed the exercise protocols. In contrast, participants in the

Mile Run-RAVLT and RAVLT-Mile Run conditions from the current study performed the recall test approximately 24 hours after finishing their exercise protocol. This relatively long delay between exercise and recall test may explain why the findings from the current study were not consistent with the literature.

The third reason the current study may be underpowered is due to the insufficient sample size. *A priori* power analysis indicated that to detect a medium effect size requires a sample size of 128. The number of potential participants for the current study was 295 and based on previous experiences at this same school, about two third of the students were willing to participate in research studies. However, only 83 students completed the study, which was unexpected. In addition, a post hoc power analysis based on statistics from 24-hr recall showed that the estimated power for the current study was 0.61, which is insufficient to detect differences among treatment conditions.

Additionally, the current study was conducted in a school setting rather than a laboratory, which may increase variability and make it harder to reach statistical significance. It is known that field research has less control over extraneous variables that might affect the results. First of all, the RAVLT was administered in school gyms and there were a few occasions where other people were walking by or passing through the gym, which may have caused distractions for participants. In addition, the low intensity activity on Day 2 after the RAVLT for the Mile Run-Recall and the no-exercise control conditions varied depending on space availability and the physical education teacher’s preference. It varied from being an indoor activity (e.g., stretching or bowling) to being an outdoor activity (e.g., throwing and catching lacrosse or Frisbee). Although all activities were low intensity and competition was not involved, the variations among them may have influenced results. Moreover, participants may have very different mile run experiences. For example, some participants paced themselves well for the most parts of their mile run and then had energy remaining for a final sprint to the finish while others alternated between fast running and walking throughout the duration of the mile. These different strategies brought different exercise experiences and, possibly, effects to the participants and may have differentially influenced the impact on memory. Also, the mile run was taking place on the school track and the weather was different for each session. Specifically, the mile run was performed in sunny, cloudy, or even a light rain day and the temperature ranged from lower sixties to high eighty degrees Fahrenheit. Although no differences on participants' mile run time and heart rate were found, there may be unobservable influences on participants due to testing conditions.

Despite that no differences on memory measures among treatment conditions were found, the exploratory analysis on effect size of 24-hr recall and recognition test may shed light on further research regarding acute exercise and memory. Specifically, compared to the no-exercise condition, Mile Run-RAVLT condition showed small to medium effect sizes on both 24-hr recall and recognition test whereas RAVLT-Mile Run and Mile Run-Recall conditions only showed smaller effect sizes. These observations are partially in line with Roig et al. (2013) meta-analysis as well as findings from empirical studies conducted by Labban and Etnier (2011) and Salas et al. (2011) where both studies showed that the facilitating effects of acute exercise on memory performance only occurs when a bout of exercise takes place prior to memory exposure or encoding phase. It should be noted that effect size from the Mile Run-Recall condition on 24-hr recall was small (Cohen's d = 0.17), but greater than the RAVLT-Mile Run condition (Cohen's d = 0.11). It is possible that performing a single bout of exercise before long-term recall may also help memory retrieval. More research is needed to examine these speculations.

In sum, the current study was designed to understand how exercise timing influences memory performance. However, no differences were observed among treatment conditions on all memory measures, indicating a single, short bout, of vigorous exercise neither facilitate memory performance nor hinder it. The short duration of exercise protocol or low power issue due to various reasons may explain the current findings. However, effect sizes for long-term memory performance may provide information for future work. Future research designed to understand how acute exercise influences memory performance is warranted. In particular, studies could keep the duration of exercise protocol same (e.g., 20 minutes) and test the influence of exercise intensity and vice versa. Thus, questions with respect to how exercise duration and intensity interact to influence memory would be more lucid. Once we have the idea of how to maximize exercise effects on memory, we could further examine whether exercise timing modulate these effects.

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APPENDIX A

TABLES AND FIGURES

Table 1. Descriptive Data for the Sample.

	Mile Run-RAVLT		RAVLT-Mile Run		Mile Run-Recall		Control	
	M	SD	M	SD	M	SD	M	SD
N (M:F)	20 (12:8)		21 (12:9)		22 (9:13)		20 (9:11)	
n of 4th grader	7		6		6		5	
n of 5th grader	3		4		3		4	
n of 6th grader	5		4		6		5	
n of 7th grader	3		4		3		3	
n of 8th grader	2		3		4		3	
Age (yr)*	11.67	1.48	12.07	1.53	12.05	1.40	11.77	1.64
BMI*	17.80	3.08	17.90	2.70	18.44	2.45	18.72	2.30
Tanner Score*	11.33	3.85	11.95	4.19	12.39	3.80	12.68	3.96
Digit Span	5.28	1.14	5.05	0.93	5.07	0.89	5.50	1.18
Mile Run Time (sec)	504.20	110.42	490.33	98.74	506.45	85.05	517.80	96.34
Heart Rate (bpm)$^{\#}$	177.60	25.58	171.50	28.82	183.82	21.11	176.00	19.12

Note. * =This descriptive data was not available for all participants because height, weight, and birth date were collected voluntarily from the parents. [#]=one participant's hear rate was not obtained, therefore only data from the rest 82 participants was included.

Table 2. RAVLT Performance in the Treatment Conditions.

	Mile Run-RAVLT		RAVLT-Mile Run		Mile Run-Recall		Control	
	M	SD	M	SD	M	SD	M	SD
Trial 1	5.55	1.70	6.00	2.28	6.09	1.48	6.30	1.49
Trial 2	8.70	2.39	7.90	2.53	7.95	1.94	7.95	2.50
Trial 3	10.30	2.41	9.62	2.44	9.95	1.91	9.55	2.21
Trial 4	11.05	2.44	10.81	2.04	11.14	2.08	10.10	2.81
Trial 5	11.75	2.73	10.67	2.20	10.95	1.70	10.65	2.78
Trial 7	10.85	2.91	9.24	3.55	9.45	2.54	9.65	3.18
24-hr Recall	10.45	2.72	8.98	2.92	9.73	2.25	9.30	2.83
Recognition	13.60	1.57	13.14	1.80	12.91	1.63	13.10	1.83

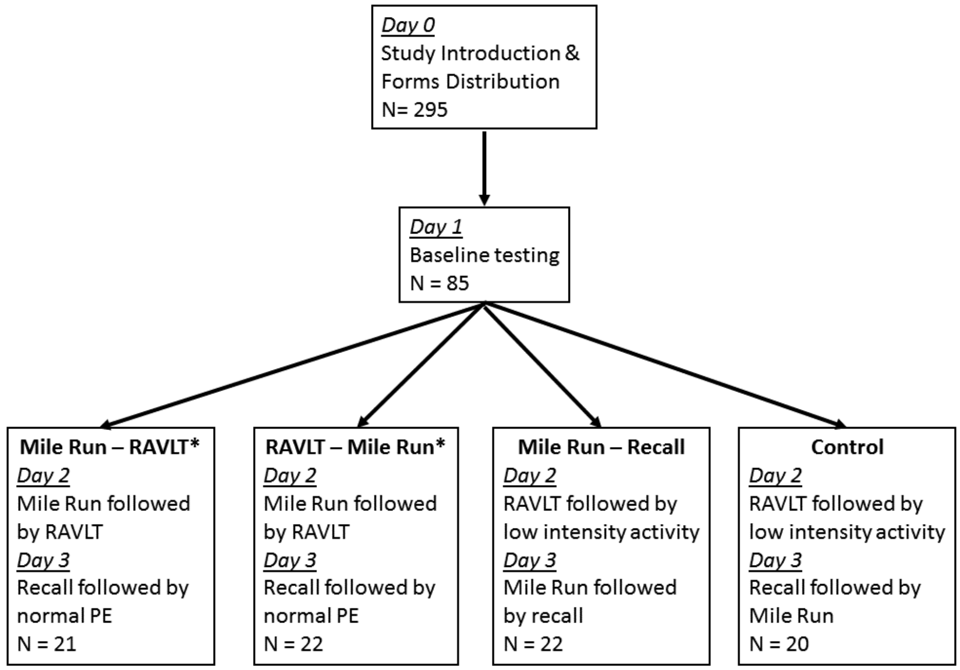

Figure 1. Study Protocol. *Note*: *=Two participants (one in Mile Run-RAVLT condition and the other in RAVLT-Mile Run condition) were not included in the final data analyses due to absence on either Day 2 or Day 3 of the study.

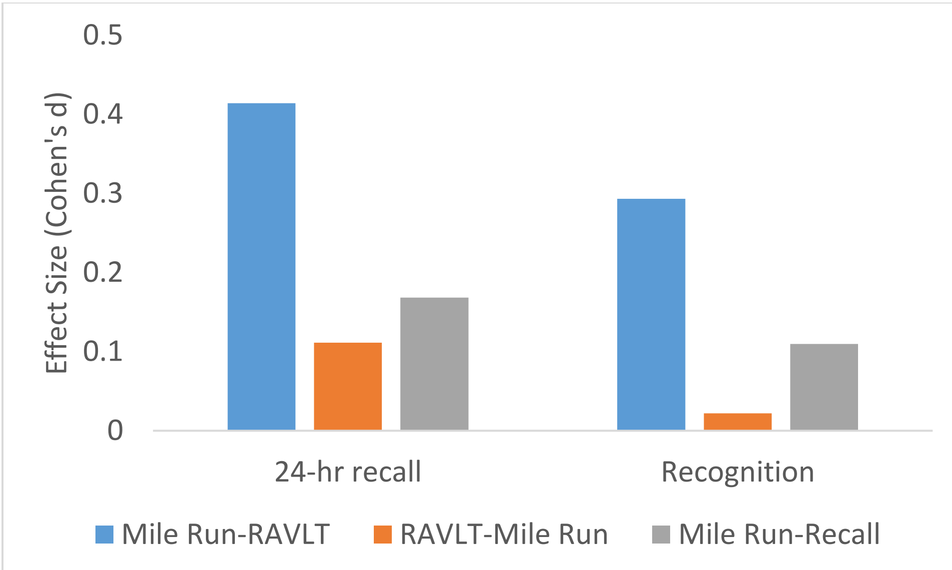

Figure 2. Effect Sizes for 24-hr Recall and Recognition Test.