THE EFFECTS OF DIFFERENT AEROBIC EXERCISE INTENSITIES ON SHORT-TERM AND LONG-TERM MEMORY RETENTION FOLLOWING A VIDEO-BASED LEARNING TASK: A PILOT STUDY

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Abstract

Research evidence regarding the effects of simultaneous exercise and learning on short- and long-term memory retention is equivocal, particularly as a function of different exercise intensities. The purpose of this pilot investigation was to compare the effects of different exercise intensities performed during a video-based learning task on short- and long-term memory retention. Seventy-two college students were randomly assigned to one of four groups: control (no exercise), and cycle exercise at light (40% HRmax), moderate (60% HRmax) and high (80% HRmax) intensity. Exercise groups watched 20 min of instructional videos on simple medical procedures while performing the cycle exercise, and the control group viewed the videos while seated at a desk. Participants completed a recall exam, immediately after viewing the videos (while cycling or sitting, as assigned) and the total correct responses (CR) were recorded to measure short-term retention. Participants then completed the same exam one week later to assess long-term retention. There was no significant difference observed for retention ($p = 0.803$) between groups across both testing sessions (control: 14.9 ± 2.3 CR; low: 15.6 ± 1.6 CR; moderate: 15.0 ± 2.6 CR; high: 15.0 ± 2.6 CR). While the exercise conditions in this pilot study did not improve short- and long-term memory retention of a video-based learning task, they also did not have a negative impact on retention. Suggestions for future study include increasing sample size, utilizing a crossover study design, addressing recall exam validity, and addressing variations in exercise intensity and duration, and participant attentiveness.

INTRODUCTION

As the landscape of didactic knowledge acquisition continues to expand beyond the traditional model of textbooks and lectures into an era of mobile devices, there may be additional options for students and professionals to incorporate physical activity into their learning approach. More than 20 years ago, it was observed that measures of students’ attitude, discipline, behavior, and creativity tend to improve in response to physical activity inclusion in school (Keays & Allison, 1995). Several, but not all, studies indicated positive effects on memory, observation, problem-solving, decision-making and
specific skills, such as reading and mathematics. Since then, more specific effects of exercise and physical activity on learning and cognition have been documented.

From an acute perspective, a single bout of exercise performed before (Labban & Ettnier, 2011; Potter & Keeling, 2005), during (Martins, Kavussanu, Willoughby, & Ring, 2013; Schmidt-Kassow et al., 2013), and after (Pesce, Crova, Cereatti, Casella, & Bellucci, 2009; Pontifex, Hillman, Fernhall, Thompson, & Valentini, 2009; Roig, Skriver, Lundbye-Jensen, Kiens, Nielsen, 2012) a learning task has been shown to improve various aspects of recall and executive function (e.g., decision making, goal planning, task or set-switching). In a recent meta-analysis of the literature, Roig, Nordbrandt, Geertsen, and Nielsen (2013) determined that exercise performed in proximity to learning tasks improved short-term memory (e.g., info is lost within seconds) and long-term memory (e.g., info recalled after lengthy temporal delays). Despite these observations, other researchers did not observe significant exercise effects on measures of executive function and memory (Coles & Tomporowski, 2008; Kubesch et al., 2003; Winter et al., 2007).

Several intertwined mechanisms may explain the effects of exercise and physical activity on learning, and the divergence in observations that have been reported. Exercise has potential to affect the brain in a comprehensive manner, not just in specific circuits tied to the motor cortex (McDonnell, Buckley, Opie, Ridding, & Semmler, 2013). For instance, it has been suggested that exercise improves the encoding and consolidation of information from short-term memory to long-term memory (Coles & Tomporowski, 2008, Roig et al., 2012, Schmidt-Kassow et al., 2013). Hötting and Röder (2013) reported that: (a) activity in frontal brain regions during executive tasks has been repeatedly observed, (b) the frontal brain regions have been found to change in response to aerobic exercise training, and (c) these changes often coincided with improved cognitive function. Many studies have been focused on the role of the hippocampus with regard to learning (Kramer, Erickson, & Colcombe, 2006). It also has been suggested that increases in blood flow to and within the brain (Scholey, Moss, Neave, & Wesnes, 1999), which can be induced by exercise, are complemented by the augmented release of cellular messengers that improve arousal and cognition, such as brain derived neurotrophic factor (BDNF), N-acetylaspartate (NAA), insulin-like growth factor-1 (IGF-1), serotonin, epinephrine and norepinephrine (Berchtold, Castello, & Cotman, 2010; Cotman & Engesser-Cesar, 2002; Hötting and Röder, 2013; Kesslak, So, Choi, Cotman, Gomez-Pinilla, 1998; Kramer et al., 2006; McMorris & Hale, 2012).

Additional considerations with respect to exercise and learning include the duration, intensity, and mode of exercise performed. Aerobic exercise appears to be the most commonly examined mode of exercise due in part to the upregulation of blood flow, catecholamines, BDNF, etc. associated with
increased cardiac output (Voss, Nagamatsu, Liu-Ambrose, & Kramer, 2011). However, other modes have been researched, such as resistance training (Pontifex et al., 2009) and stretching (Dustman et al., 1984). In all cases, it appears that aerobic exercise was a more effective mode. In separate reviews, Brisswalter et al. (2002) and Tomporowski (2003) both indicated that 20-60 min of exercise performed in proximity to a learning task improved cognition and that low to moderate exercise intensities elicited physiological responses great enough to improve cognition, such as catecholamine release (e.g., epinephrine) and upregulation of neurotropic factors (e.g., BDNF). In addition, exercise performed at higher intensities for shorter durations has been shown to elicit cognitive improvements. Roig et al. (2012) found that a single bout of high intensity cycling intervals (3 x 3 min) performed in proximity to instruction of a motor skill improved long-term retention of that skill. Lastly, exercise protocols that were too long or too intense were more likely to induce dehydration and fatigue, which mitigated the positive effects of exercise on cognition, or perhaps even decreased cognition (Brisswalter et al., 2002; Tomporowski, 2003). For instance, Kennard and Woodruff-Pak (2012) observed impaired spatial memory in response to high impact stressful exercise and Lo Bue-Estes, Burton, Leddy, Wilding, and Horvath (2008) observed that working memory declined during and immediately after exhaustive exercise was performed at maximal aerobic capacity.

**Problem Statement, Purpose, and Significance of the Study**

Most of the reviewed literature indicates that aerobic exercise, performed in proximity to a learning task, can improve cognition. Few studies have analyzed the effect of simultaneous exercise and learning on short- and long-term memory, and no researchers have documented this as a function of different exercise intensities. On many academic campuses nationwide, physical activity resources are readily available, but often neglected due to study time commitments. It could be of benefit to students to identify an effective strategy for simultaneous exercise and learning. Therefore, the purpose of this pilot investigation was to compare the effects of three different aerobic exercise intensities performed during a video-based learning task on short- and long-term memory retention.

**METHODS**

**Participants**

Male and female students in health-oriented majors (e.g., nursing, exercise science, health science, and community health) at two, four-year universities were identified as the target population for the pilot study. Prior to recruitment, the study was approved by a university Institutional Review Board. Convenience sampling was utilized (e.g., word of mouth) to recruit potential participants for the sample population. Selection criteria required participants to be within the ages of 18-24 years and free
of chronic diseases or health conditions that could have altered exercise responses. Participants completed a pre-participation questionnaire based on the joint recommendations of the American College of Sports Medicine and American Heart Association for determination of eligibility (American College of Sports Medicine, 1998).

Ultimately, 72 eligible participants (males = 23, females = 49; age: 20.6 ± 1.9 years) volunteered for, and completed, the study protocol. All participants were provided written and verbal instructions 48 hrs prior to testing and gave written consent for participation. Upon admittance into the study, participants were randomly assigned to one of four testing groups: (a) control (no exercise), (b) low-moderate intensity exercise (40% of maximal age-predicted heart rate [HR_{max}]), (c) moderate intensity exercise (60% HR_{max}), and (d) high intensity exercise (80% HR_{max}). The equation to determine HR_{max} was the commonly known [220 – age = HR_{max}] that originated from Fox and Haskell (1970) and Fox, Naughton, and Haskell (1971).

Familiarization Procedures

All participants initially performed a familiarization session to learn testing session procedures and establish appropriate ergometer settings for their assigned intensity. At the beginning of the familiarization session, all participants performed a sample learning task that was similar to, but different than, the one used in the subsequent testing sessions. The learning task involved observation of a five min instructional video on blood pressure assessment (4yourCNA, 2012) while in a seated, resting position. The instructional video was chosen based on similarities in presentation style and content relevance to the videos used in the testing sessions. Immediately after the viewing the instructional video, participants answered sample exam questions similar in style (e.g., multiple choice) to those that would be used in the testing sessions. The combined purpose of the sample video and questions was simply to provide clarity on the sequence and instructions participants would be exposed to during the testing sessions in order to mitigate procedural understanding as a confounding variable. Following the sample video and questions, the participants (except those in the control group) performed approximately 10 min of cycle ergometer exercise at the assigned intensities. The duration of this exercise bout was partially dependent on the time needed to determine the appropriate ergometer workload that would elicit the prescribed intensity for each participant.

Experimental Procedures

Prior to arrival for the testing sessions, all participants were asked to refrain from strenuous exercise, obtain a restful night of sleep, remain well hydrated, and eat regularly. Furthermore,
participants were provided a list of common caffeinated food items and were asked to refrain from caffeine consumption 24 hrs prior to testing. One week separated both testing sessions.

First Testing Session. During the first testing session, participants in the exercise intervention groups completed a 3-5 minute warm up on the cycle ergometer at a self-selected intensity. Immediately following the warm-up, the participants completed a 20 min exercise bout at the prescribed intensity. Exercise intensity was monitored telemetrically via a chest-strap heart rate monitor (Polar T31, Polar Electro Inc., Lake Success, NY, USA) and recommendations to increase or decrease exertion were made during the bout to help keep participants at the assigned intensity. During the 20 min exercise bout, two instructional videos were shown to the participants (AshtonMoh, 2011; EssentialsConference, 2012). The videos provided instruction on common medical procedures (e.g., lumbar punctures and shoulder relocation) that were anticipated to be of great interest to the participants (given their academic majors), but outside of their current scope of knowledge and practice. In total, the videos lasted the exact duration of the 20 min exercise bout. Participants in the control group watched the same videos without simultaneous exercise, while seated in a chair. At the conclusion of the videos, all participants completed a short multiple-choice exam designed by the researchers using content validity to assess recall of the viewed medical procedures. Upon completion of the exam, the participants were scheduled for the second testing session exactly one week later. Participants were asked to not discuss the video content or exam with other participants in the study. Participants also were asked not to study the content from the videos prior to the second testing session.

Second Testing Session. During the second testing session, all participants completed the same multiple-choice exam that was provided in the first testing session in order to assess long-term memory retention. The participants were given the exam immediately upon arrival to the session and completed the exam while sitting in a chair.

Data Analysis

Short-term (ST) and long-term (LT) memory retention of the video content were assessed via the number of correct responses (CR) recalled on the exam completed in the first and second testing sessions. A factorial Analysis of Variance (ANOVA) with repeated measures was used to determine the existence of significant differences between and within testing groups over time. Significance for the ANOVA was set at $p \leq 0.05$. 
**RESULTS**

Descriptive statistics for ST and LT memory retention are summarized by testing group in Table 1. There was not a significant difference for retention ($p = 0.803$) between groups across testing sessions (control: $14.9 \pm 2.3$ CR; low: $15.6 \pm 1.6$ CR; moderate: $15.0 \pm 2.6$ CR; high: $15.0 \pm 2.6$ CR). However, there was a significant difference ($p = 0.000$) between ST and LT memory retention across all testing groups (ST: $15.6 \pm 2.2$ CR; LT: $14.8 \pm 2.4$ CR), which indicated that memory retention decreased from the first to second testing sessions. In addition, there was no significant difference ($p = 0.976$) noted for the interaction between time x group.

<table>
<thead>
<tr>
<th>Group</th>
<th>Short-term Retention (CR)</th>
<th>Long-term Retention (CR)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control (n = 18)</td>
<td>$16.0 \pm 1.7$</td>
<td>$14.8 \pm 2.4$</td>
</tr>
<tr>
<td>Low intensity (n = 17)</td>
<td>$16.0 \pm 1.4$</td>
<td>$15.1 \pm 1.8$</td>
</tr>
<tr>
<td>Moderate intensity (n = 19)</td>
<td>$15.4 \pm 2.7$</td>
<td>$14.7 \pm 2.5$</td>
</tr>
<tr>
<td>High intensity (n = 18)</td>
<td>$15.4 \pm 2.5$</td>
<td>$14.6 \pm 2.8$</td>
</tr>
</tbody>
</table>

**DISCUSSION**

The purpose of this pilot investigation was to compare the effects of aerobic exercise intensity performed during a video-based learning task on short- and long-term memory retention. The results do not demonstrate significant differences between the three exercise intensity groups or control group on memory retention. Although no single exercise intensity emerged as superior to another with regard to its effect on memory retention, it must be mentioned that simultaneous exercise and learning (across a variety of intensities) did not appear to negatively impact short- and long-term memory retention. These results are further discussed in the following sections.

**Intensity and Duration of Exercise**

Findings from previous research suggested that 20-60 min of exercise performed at low to moderate exercise intensities elicited physiological responses that could improve cognition (Brisswalter et al., 2002; Tomporowski, 2003). In addition, exercise performed at higher intensities was shown to benefit cognition (Roig et al., 2012). In this pilot study, 20 min of exercise bouts performed at 40%, 60%, and 80% of HR$_{\text{max}}$ were utilized to examine the effect of exercise intensity on short- and long-term memory retention. Longer bouts, such as 40 or 60 min, were avoided due
to the risks of dehydration or fatigue on cognition, particularly at higher exercise intensities (Brisswalter et al., 2002; Tomporowski, 2003).

Though no data collection was in place to assess the underlying mechanisms of cognition, the possibility that cellular messengers were not upregulated as expected or simply did not have a meaningful effect on short- and long-term memory should be considered. For instance, McDonnell et al. (2013) hypothesized increases in BDNF in response to exercise performed at low to moderate intensities. However, they observed decreases in BDNF for all participants. Schmidt-Kassow et al. (2013) observed that light to moderate intensity exercise augmented vocabulary encoding, but BDNF levels failed to account for this improvement. Similarly, Kennard and Woodruff-Pak (2012) indicated that the improvements observed for learning and memory in mice were independent of exercise intensity, exercise duration, and BDNF levels.

Independent of the role of cellular messengers on cognition, it also is plausible that participant fitness levels influenced the perceived exercise intensities. For instance, participants were initially assigned to testing groups in a random fashion and no fitness prerequisites or assessments were required as a condition of participation. However, during familiarization it was determined that two participants assigned to the high intensity exercise group were unable to perform the prescribed exercise intensity. Though the intent of familiarization was not to place participants in testing groups, the researchers made the decision to re-assign these two participants to a lower intensity exercise group in order to complete the study protocol. All other participants were able to complete the exercise testing as originally assigned. Since no fitness prerequisites or assessments were conditional of participation, and in light of the re-assignment of two participants, it must be noted that fit participants who performed exercise at 60% or 80% $HR_{max}$ may have perceived the intensity as lighter than unfit participants who may have perceived the same intensity as hard. As indicated by Tomporowski (2003), there is a demonstrable effect of fitness on cognition. Although no standardized measures were used in this pilot study to ascertain fitness or perceived intensity, anecdotal comments gleaned from participants suggest that there were variations in both. Therefore, it is possible that variances in participant fitness and perceived intensity affected the standardization and effects of exercise intensity between groups.

**HR$_{max}$ Prediction for Exercise Prescription**

The equation $[220 – \text{age} = HR_{max}]$ used for exercise prescription in this pilot study stems from early reviews by Fox and Haskell (1970) and Fox, Naughton, and Haskell (1971). Notably, this equation appears to have been determined arbitrarily and has been found to both under- and over-predict maximum heart rate in many populations (Nes, Janszky, Wisløff, Støylen, & Karlsen, 2012;
Robergs & Landwehr, 2002; Tanaka, Monahan, & Seals, 2001). On this basis, several attempts have been made to establish a more accurate prediction of maximum heart rate (Robergs & Landwehr, 2002). One of the more widely used HR\(_{\text{max}}\) prediction equations [HR\(_{\text{max}} = 208 - (0.7 \times \text{age})\)] that emerged from these efforts was proposed by Tanaka et al. (2001), however, it too has been shown to have large variability. With respect to the multitude of reviews that have been conducted on this topic, no single equation has been found to accurately and reliably predict HR\(_{\text{max}}\) across several populations (Sarzynski et al., 2014).

Despite the known variability of the Fox HR\(_{\text{max}}\) equation, it was used in this investigation for its pragmatic simplicity in exercise prescription. One of the underlying intents for this pilot study was to investigate the feasibility of a simultaneous exercise and learning strategy for students. Therefore, it was decided that a simple method to determine and monitor exercise intensity would have high practical value for the target population. In light of the observed variance in perceived exercise intensities across participants, the researchers acknowledge the possibility that use of the Fox HR\(_{\text{max}}\) equation may have acted as a confounding variable. For this reason, and because of the validity and reliability issues attributed to other HR\(_{\text{max}}\) predictions, alternative metrics to standardize exercise prescription should be considered for further investigations of this nature.

**Attentiveness to the Learning Task**

In this pilot study, the learning task was approximately 20 min long, divided between two videos that were approximately 10 min each. A popular notion is that attention declines after 10-15 min, as indicated by previous research and anecdotal reports from the classroom (Wilson & Korn, 2007). However, in their review of relevant research, Wilson and Korn (2007) indicated there is little empirical support for the notion of a 10-15 min attention span. With respect to this pilot investigation, it is possible that the total learning task was too long to sustain optimal attention levels or, conversely, division of the learning task between two videos within the 20 min optimized attention levels. In addition, Wilson and Korn indicated that receptivity to learn new information and styles of attentiveness and engagement during a learning task are more important than lesson time. Given the academic major and professional aspirations of the participants, they expressed a high degree of "buy-in" with the learning task. Most of the participants commented that the videos were novel and interesting, and the participants in all testing groups appeared to be visually attentive throughout the learning task. However, no measures were taken to assess or control attentiveness in this pilot study, and it could be of value to address this in future investigations.
Testing and Study Design Validity

Within the domains of psychological and educational research, there are standardized tests to assess short- and long-term memory retention, such as the Memory Assessment Scales battery (Williams, 1993) or the Sternberg Memory Task (Martins et al., 2013), which have been validated for clinical assessment. In this pilot study, a multiple-choice exam was created by the researchers to assess short- and long-term retention of the primary learning objectives from each video. Notably, only content validity was used to ascertain the relevance and appropriateness of this exam. The decision to forgo use of previously validated assessments of memory retention was one based on practicality. The researchers desired this pilot investigation to be as relevant to the types of learning tasks already undertaken by participants in the sample population. Though no anecdotal evidence was obtained to suggest a lack of validity, it must be acknowledged that the exam used in this pilot investigation was not assessed for validity and reliability, which may have resulted in questions that were too easy, too hard, or too abstract. Consequently, the exam used in this pilot may not have been as accurate of an assessment of short- and long-term memory retention as previously validated tools.

Along these lines, long-term memory typically has been assessed between 12 min (Coles & Tomporowski, 2008) and two weeks (Berchtold et al., 2010) after a learning task in the consulted literature. In this pilot study, long-term memory retention was assessed one week after the video-based learning task for practicality. In accordance with the findings of previous literature, there was a decline in memory retention in this pilot investigation, however, the decrease was statistically similar for all testing groups. Assessment of the video content a week after viewing seemed applicable to the target population, who might desire to use simultaneous exercise and learning to improve retention of class material for subsequent exams.

The design of future investigations stemming from this pilot study also could be improved to increase internal validity. Random assignment of participants into different testing groups is a common research design consideration to address internal validity. In this pilot study, random assignment initially was used to form the testing groups. However, as mentioned earlier, it was determined that two participants could not complete the 20 min exercise bout at the assigned intensity and were assigned to lower intensity testing groups in a non-random fashion. A cross-over study design where all participants are exposed to each testing condition, thereby serving as their own controls, could have increased the internal validity of the present study design. However, cross-over designs require more time to complete and under the circumstances of this pilot
investigation, that additional time was not available. Therefore, the researchers relied on random assignment, to the best of their abilities, to address internal validity.

**Statistical Considerations**

Although 72 participants completed the study protocol, the sample size was still too low to counter the small observed effect size ($d = 0.003$). Consequently, beta was extremely high ($\beta = 0.938$), which means there was a large probability that a Type II error occurred. In other words, it cannot be inferred with confidence that the present research conditions would not elicit a different effect on short- and long-term memory retention in another study of similar design or in the real world for the broader target population.

**Future Research Recommendations**

Based on the considerations for the present pilot investigation, further examination would be useful to better identify and understand the effects of simultaneous exercise and learning for students. At the least, future research investigations may benefit from: (a) recruitment of more participants to decrease the risk of a Type II error in interpretation of results, (b) additional pilot testing to ascertain the validity and reliability of novel testing instruments or use of standardized memory assessments, (c) a cross-over study design to improve internal validity, (d) well-defined fitness criteria and eligibility screening to standardize participant fitness, and (e) use of a method alternative to $HR_{max}$ prediction equations to improve the accuracy and standardization of the exercise prescription.

**Conclusion**

Under the research conditions of this pilot study, variations in exercise intensity did not improve or reduce short- and long-term memory retention of a video-based learning task. Further investigations are recommended to verify the efficacy of simultaneous exercise and learning as a strategy for students to maintain or improve health, fitness, and learning.

**REFERENCES**


