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Original Research

Acute Exercise on Reversal Learning

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Abstract

***Objective**:* Reversal learning requires an individual to alter their behavior when previously learned reward-based contingencies are reversed. Reversal learning is heavily influenced by cognitive flexibility, which has been shown to be enhanced with acute exercise. However, minimal work has directly evaluated the effects of acute exercise on reversal learning, which was the purpose of this experiment.

***Methods**:* A between-subject randomized controlled intervention was employed. Participants (N=60) were randomized into one of three groups, including a control group, moderate-intensity exercise and vigorous-intensity exercise. The exercise bout lasted 15-min in duration. Reversal learning was evaluated using the Iowa Gambling Task, occurring shortly after the exercise session.

***Results**:* There was no main effect for group, $F(2, 57) = .63$, $p = .53$, $\eta^2_p = .02$, or group by learning interaction, $F(5.94, 169.3) = .16$, $p = .98$, $\eta^2_p = .006$, but there was a significant main effect for learning, $F(2.97, 169.3) = 11.21$, $p < .001$, $\eta^2_p = .16$.

***Conclusion**:* Across the learning blocks, participants, on average, improved their reversal learning. However, this enhanced reversal learning effect was not influenced by acute exercise.

Keywords
Cognition; cognitive flexibility; physical activity

1. Introduction

Emerging research demonstrates that acute exercise is associated with enhanced memory performance [1-7]. Mechanisms of this potential effect are multifold, including, for example, exercise-induced neuronal excitability, transcription factor expression, and growth factor production [8]. Although exercise has been shown to potentially help enhance the retention of learned information, very limited research has evaluated whether acute exercise can enhance the actual learning process, i.e., enhance learning.

Herein, we evaluate whether acute exercise is associated with enhanced learning using the well-established Iowa Gambling Task (IGT) [9]. This task specifically evaluates reversal learning, which requires an individual to alter their behavior when previously learned reward-based contingencies are reversed. Reversal learning is an important component of executive function, which has been shown to be positively influenced by acute moderate-intensity [10, 11] and high-intensity [12, 13] exercise. Specifically, the cognitive flexibility component of executive function is an important prerequisite for reversal learning [14] and acute exercise has been shown to subserve cognitive flexibility [15-17]. Further, chronic high-fat diet consumption has been shown to impair reversal learning and reduce BDNF levels [18], yet we have shown that exercise can counteract these effects [19]. Collectively, there is theoretical support for a relationship between acute exercise and reversal learning. However, given the lack of research on this topic, the purpose of this investigation was to evaluate the effects of acute exercise on reversal learning.

2. Methods

2.1 Study Design

A between-subject randomized controlled intervention was employed. Participants were randomized into one of three groups, including a control group, moderate-intensity exercise and vigorous-intensity exercise. This study was approved by the authors' ethics committee. All participants provided written, informed consent.

2.2 Participants

The study included 60 participants (N=20 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 40 yrs.

Additionally, participants were excluded if they:

Self-reported as a daily smoker [20, 21];
Self-reported being pregnant [22];
Exercised within 5 hours of testing [23];
Consumed caffeine within 3 hours of testing [24];

Had a concussion or head trauma within the past 30 days [25];
Took marijuana or other illegal drugs within the past 30 days [26];
We're considered a daily alcohol user (>30 drinks/month for women; >60 drinks/month for men) [27].

2.3 Exercise Groups

The moderate intensity exercise group exercised on a treadmill at 50% of heart rate reserve (HRR) for 15 minutes. The vigorous intensity exercise group exercised at 80% of HRR for 15 minutes. These two respective intensities (50% and 80% of HRR) represent moderate and vigorous-intensity exercise [28].

The equation for HRR that was utilized is:

HRR = [(HRmax – HRrest) * % intensity] + HRrest

Heart rest (HRrest) was determined from the average of two resting heart rate measurements (after 5 and 6 minutes of seated rest) using a Polar (F1) heart rate monitor. Heart rate max (HRmax) was estimated from Tanaka et al. [29] 208 – (0.7*age).

2.4 Control Group

The control group engaged in a seated task (Sudoku) for 20-minutes. This involved playing a medium-level, on-line administered, Sudoku puzzle. The website for this puzzle is located here: https://www.websudoku.com/. We have experimental evidence that playing this puzzle does not prime or enhance memory function [30].

2.5 Learning Assessment

In the IGT, participants are asked to choose from one of four different deck of cards to win as much money as possible. While completing this task, it is expected that participants will learn to discriminate advantageous decks (Decks C and D) from disadvantageous decks (Desk A and B). Learning from this task requires that participant to adjust their behavior based on the feedback provided (i.e., based on how much money is won/lost from the card selected). Further, adaptive behavior requires the inhibition of prepotent responses, as participants learn to forego the high monetary rewards (immediately attractive options that are also associated with high losses) in favor of the low to moderate monetary rewards (initially less attractive options that are associated with reduced losses and long-term profit). The shift in the prepotent response during this learning process is conceptualized as the reversal learning effect [9].

The IGT was completed on a computer using PsyToolkit. Participants completed 100 trials (i.e., selected 100 cards) of the IGT (lasting approximately 5-minutes in total) using the same IGT instructions as reported elsewhere [31]. The outcome measures included the mean net score, Gambling Index, which is the number of choices from the good decks, C and D, minus the number of choices from the bad decks, A and B. Results are presented for five separate blocks (Block 1, trials 1-20; Block 2, trials 21-40; Block 3, trials 41-60; Block 4, trials 61-80; and Block 5, trials 81-100). Higher index scores are indicative of a better reversal learning effect.

2.6 Protocol for Visits

As stated, participants were randomly assigned to one of three groups, including a control group, moderate-intensity exercise, or vigorous-intensity exercise. Protocol details for these three groups are as follows:

Control Group

- Sudoku for 20-minutes
- Commence IGT

Moderate-Intensity

- Acute treadmill exercise for 15-minutes at 50% of HRR
- Rest for 5-minutes
- Commence IGT

Vigorous-Intensity

- Acute treadmill exercise for 15-minutes at 80% of HRR
- Rest for 5-minutes
- Commence IGT

2.7 Statistical Analysis

All statistical analyses were computed in Jasp (v. 0.10.0). A 3 (condition) x 5 (blocks) two-factor mixed-measures ANOVA was computed. In the ANOVA model, the sphericity assumption was violated, and as such, we report the Huynh-Feldt corrected values. Statistical significance was set at an alpha of 0.05. Partial eta-squared (η2p) was calculated as an effect size estimate.

3. Results

Table 1 displays the characteristics of the sample. Participants were similar across the three experimental groups. That is, age (p = 0.69), gender (p = 0.29), race-ethnicity (p = 0.70), and BMI (p = 0.72) were not statistically significantly different across the three groups.

Table 1 Sample characteristics across the experimental groups.

Variable	Control	Moderate-Intensity Exercise	Vigorous-Intensity Exercise
Age, mean years	20.8 (0.8)	20.9 (1.2)	21.1 (1.1)
Gender, % Female	75.0	75.0	55.0
Race-Ethnicity, % White	75.0	90.0	75.0
BMI, mean kg/m^2	24.9 (5.4)	25.3 (4.8)	24.2 (3.8)

Table 2 and Figure 1 display the reversal learning scores. In the 3 (condition) x 5 (blocks) two-factor mixed-measures ANOVA, with group as the between-subjects variable and the learning blocks (1-5) as the within-subject variable, there was no main effect for group, $F(2, 57) = .63$, $p = .53$, $\eta^2_p = .02$, or group by block interaction, $F(5.94, 169.3) = .16$, $p = .98$, $\eta^2_p = .006$, but there was a significant main effect for block, $F(2.97, 169.3) = 11.21$, $p < .001$, $\eta^2_p = .16$. Bonferroni-corrected post-hoc tests indicated that learning for block 1 was significantly lower than block 3 (p

< .001), block 4 (*p* < .001) and block 5 (*p* < .001), and similarly, learning for block 2 was significantly lower than block 4 (*p* = .04).

Table 2 Reversal learning scores (mean (sd)) across the experimental groups.

Gambling Index Score	Control	Moderate-Intensity Exercise	Vigorous-Intensity Exercise
Block 1	2.2 (6.0)	-.60 (7.4)	0.10 (6.7)
Block 2	4.7 (9.3)	2.7 (10.1)	2.1 (9.1)
Block 3	7.8 (9.9)	5.7 (10.3)	3.8 (10.3)
Block 4	8.5 (10.0)	5.9 (12.0)	5.8 (11.4)
Block 5	8.0 (10.2)	6.5 (12.5)	5.2 (11.4)

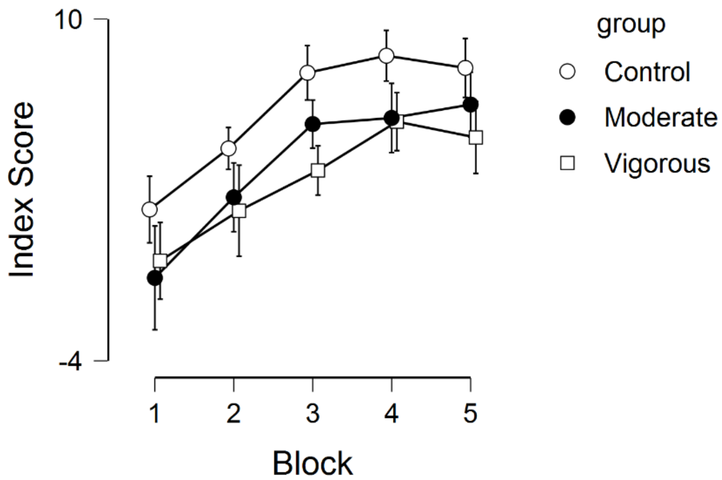

Figure 1 Schematic of the reversal learning scores across the 5 blocks and experimental groups. Error bars represent standard errors.

4. Discussion

The present study, written as a brief report, aimed to evaluate whether acute exercise can enhance a cognitive-related reversal learning effect. The motivation for this experimentation came from past work demonstrating that acute exercise can enhance the functional connectivity of neurons [32], improve cognitive flexibility [15-17], as well as improve memory function [1-7], all of which are important for cognitive-related learning. In the present experiment, our main findings were as follows. Across the learning blocks, participants, on average, improved their reversal learning. However, this enhanced reversal learning effect was not influenced by acute exercise.

Before discounting the potential effects of exercise on learning, future work may wish to extend the acute bout of exercise. Although a 15-min bout of exercise has been shown to enhance memory function [1-7], perhaps a more robust stimulus (longer duration) is required in this context. Further, emerging work demonstrates that open-skilled exercise vs. closed-skilled exercise may have a differential effect on cognition [33]. Open-skilled exercise involves unpredictable movement patterns (e.g., racquetball), whereas closed-skilled exercise involves more predictable movement patterns (e.g., treadmill exercise). Open-skilled exercises have been shown to have a greater effect on markers of synaptic plasticity, such as brain-derived neurotrophic factor [34], and as such, these exercises may have a greater effect on learning.

Limitations of this study include the homogeneous sample of participants, limiting generalizability to other populations. As such, future work on this topic should consider other populations (e.g., older adults) that may be more likely to observe learning effects from acute exercise. Further, we did not employ a baseline measure of reversal learning, which is a limitation of our study. However, we were concerned that a baseline assessment would induce a learning effect for our post-exercise learning measure. Strengths of this investigation include the experimental design, study novelty, and evaluating multiple exercise intensities.

In conclusion, a reversal learning effect was observed, but this effect was not influenced by acute exercise. Notably, high-intensity acute exercise also did not impair reversal learning. Future work should evaluate different exercise modalities on reversal learning, as well as investigate the long-term effects of habitual exercise on learning. It is possible that long-term exercise, or longer duration acute exercise, may be needed to augment such learning effects in this population. Perhaps our short duration exercise stimulus was not sufficient to influence reversal learning in this relatively healthy population. Future work should continue to investigate this paradigm to evaluate if there is an optimal exercise stimulus to elicit changes in reversal learning. This is an area of research with important individual and societal implications, as reversal learning is associated with various health-related behaviors, such as impulsive and compulsive behaviors [35].

Author Contributions

Author C.S. collected the data. Author P.L. conceptualized the study, analyzed the data and prepared the initial draft of the manuscript.

Competing Interests

We have no conflicts of interest and no funding was used to prepare this manuscript.

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