**The differential effects of an acute bout of steady state aerobic or HIIT exercise on cognitive function in sleep deprived young adults**

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**Abstract**

*Objectives:* The purpose of this research is to examine whether a single acute bout of aerobic exercise has positive effects on cognitive function in sleep deprived young adults. This research also examines the how different types of aerobic exercise may have an effect on cognitive function.

*Design:* Self-selected sleep deprived young adults randomly assigned to different experimental sequences involving no exercise, steady state aerobic exercise, and high intensity interval training exercise.

*Methods:* Young adults (n=19, 7 males and 12 females) were randomly assigned to one of three groups, each with a different sequence of taking two cognitive tests after either no exercise, aerobic exercise, or high intensity interval training exercise. Participants completed the Stroop test (selective attention) and a two-back working memory test (short-term memory).

*Results:* Sleep deprived participants showed significant decreases in Stroop (i) response time after both steady state aerobic (p=0.004) and HIIT exercise (p=0.040) treatments and in N-Back response times after steady state exercise (p=0.003) compared to no exercise.

*Conclusion:* An acute bout of steady state aerobic exercise improved attention, executive function and working memory in sleep deprived college aged adults. HIIT exercise exclusively improved attention and executive function in the same subjects.

## Introduction

Sleep deprivation is a prevalent issue among college students in the U.S. [19]. Young adults are more affected by sleep deprivation than older adults [10]. Furthermore, the implications of sleep deprivation in college students are highly consequential for performance. In one study performed with college students, “short sleepers (<6 h per night) obtained lower grades (GPA: 2.74) than long sleepers (>9 h per night; GPA:3.24), indicating that those who have more total night sleep tend to have higher grades” [5]. This seems to be a logical implication, given the multitude of ways in which sleep deprivation impairs cognitive function.

The major consequences of sleep deprivation negatively affect an individual behaviorally, psychologically, and physiologically [18]. Surveys and meta-analyses of the current research on sleep deprivation indicate that sleep deprivation can cause decreased sleep latency (as can be measured by alpha wave attenuation [12]), involuntary microsleeps, decreased attention, cognitive and response time slowing with increased error, impaired learning and higher order thinking, higher rate of cognitive fatigue regardless of task, and loss of situational awareness [6]. Though there is not a large body of research on chronic sleep deprivation, studies indicate that sleeping for six or less hours per night for two weeks results in an equivalent decrease in cognitive performance to that elicited by a full 48 hours of total sleep deprivation [16].

There is a large body of research indicating that exercise improves cognitive function. Based on fNIRS, an acute bout of exercise has a positive effect on many of the same regions impaired by sleep deprivation [3]. This seems to suggest that an acute bout of exercise can in a sense “undo” the harmful effects of sleep deprivation. If exercise can overcome some or most of the cognitive impairment caused by sleep deprivation, an acute bout of exercise within the hour before a test or any task requiring attention and short-term memory could be an incredibly useful tool for sleep deprived college students. The current body of research has mainly focused on aerobic exercise. While a large number of the studies have used either chronic aerobic exercise or fit individuals [4, 9], there are many studies showing an increase in cognitive performance with an acute bout of aerobic exercise and one study in particular indicating that a 20 minute bout of exercise at 65% $VO_2max$ elicits the greatest increase in cognitive performance [4].

Approaching the research from an applied perspective, it is clear that exercise in daily life is often widely varied and may not always be aerobic in nature. With the rise in popularity of fitness regimes such as CrossFit and High Intensity Interval Training (HIIT), there is an increased likelihood that a person's exercise regime may be short and vigorous in nature rather than aerobic. HIIT is characterized by, "repeated bouts of short duration, high-intensity exercise intervals intermingled with periods of lower intensity intervals of active recovery" with high-intensity exercise being at least 80% of maximum heart rate [21]. While little research exists to provide any link between these specific types of training and increased cognitive performance, there is evidence indicating that "short but vigorous bouts of exercise...may raise alertness levels enough to "get over the hump" without compounding fatigue" [8]. Furthermore, research has shown that an acute bout of high intensity aerobic interval exercise improves selective attention when measured by the Stroop "color word" test in middle-aged adults [1].

Based on the compendium of research on the effects of both sleep deprivation and an acute bout of exercise on cognitive performance, there is a general consensus that sleep deprivation causes significant decreases in cognitive function, while exercise has a significant positive effect on cognitive performance. With this evidence, it seems plausible to suggest that exercise could have the effect of "undoing" some of the negative effects of sleep deprivation in order to boost cognitive performance. Very few studies, however, have examined the interaction between sleep deprivation and an acute bout of exercise in relation to cognitive performance in untrained young adults.

The purpose of this study is to test the effects of an acute bout of exercise on the cognitive performance of sleep deprived college students. Based on previous studies, we hypothesize that an acute bout of moderate intensity or HIIT exercise will improve both cognitive function and alertness in sleep deprived college students.

## Methods

*Study Sample:* The study sample consisted of seven males and twelve females ages 17-21 years old. Participants were students from Wheaton College who participated to receive extra credit in their Wellness course (AHS 101). Participants were asked to record the number of hours of sleep they got each night for the week prior to testing. The participants were divided into three groups, each group performing the testing protocol in a different order. Group A did a session with no exercise, aerobic exercise, and then HIIT. Group B did a session with aerobic exercise, HIIT, and then no exercise. Group C did a session with HIIT, no exercise, and then aerobic exercise. The order for different groups can be seen in Table 1. Depending on how many hours participants slept on average, participants were considered either controls ( >7 hours/night), or sleep deprived (<7 hours/night). We chose these parameters instead of greater or less than six hours because the average sleep in a week for many college students is skewed by greater sleep on the weekends. Five males and six females were controls and two males and six females were sleep deprived.

*Experiment Protocol:* The study was conducted in either the morning (9:15 am), the afternoon (1:15pm), or the evening (7:00-9:00pm). The majority of the trials took place in the evening. Participants came in for testing either two or three separate times in the time frame of one week. The participants were tested using a Stroop test to assess attention and executive function, and a two-back working memory test to assess short-term memory as indicators of performance in cognitive function. These tests were accessed at a free online testing website [20]. Participants were required to complete 100 trials of the Stroop test and 100 trials of the two-back working memory test to compare their cognitive function either after no exercise, after steady state aerobic exercise, or after high-intensity interval training (HIIT) exercise. As was stated earlier, each participant completed the testing protocol in one of three sequences in order to offset any learning effect that may have come from taking the cognitive tests multiple times.

For the test without exercise, the participants were tested with no activity prior to the test. For the test with steady state aerobic exercise, participants used a cycle ergometer and performed a 5 minute warm-up followed by 10 minutes at 65% of their maximum heart rate and a 5 minute cool down [4]. They performed the cognitive tests as soon as possible after exercise. For the test with high-intensity interval training exercise, participants performed 5 sets of a 1 minute interval at 80% of maximum heart rate followed by a 1 minute interval of active recovery at 40% maximum heart rate on a cycle ergometer. As soon as possible after exercise, they performed the cognitive test series. This protocol was adapted from the Change et al. study, but the duration of the steady state exercise was shortened in order to match the duration of the HIIT exercise.

*Statistical Analysis:* All the collected data was analyzed using one way analysis of variance ANOVA with multiple groups being plotted on SigmaPlot. Power of the performed test was considered statistically significant if it was less than 0.05 in all of the results.

## Results

All test subjects completed the steady state aerobic, high intensity interval exercise, and no exercise treatment. Averaged results for four relevant data points from each cognitive test were compared to determine the effect of each exercise protocol relative to the others. These four data points were normal Stroop response time (Stroop (n)), Stroop response time for color interference (Stroop (i)), n-back response time (N-Back Time), and percent correct in the n-back test (N-Back %).

As displayed in Figure 1, faster response times accompanied by higher percentage of correct responses tended to occur after exercise compared to when participants did not exercise before the tests. While these data trended toward significance, only Stroop (i) and N-Back Time showed significant enhancements in cognitive performance after exercise. For the Stroop (i) response time, this improvement was significant for both steady state aerobic ($p=0.004$) and HIIT ($p=0.040$) exercise protocols, and for

N-Back Time there was a significant improvement compared to no exercise following the steady state aerobic exercise protocol ($p=0.003$). Treatment response was also compared within each group to determine whether there may have been a learning effect that could have skewed the data or if each group consistently showed improvements after exercise (meaning that there was a high association between exercise and improved scores rather than just between subsequent tests and improved scores). Group A (see Table 1) saw a significant improvement in all four test categories ($p<0.001$ to $p=0.030$). Group B saw significant improvements compared to no exercise only after steady state aerobic exercise treatment in the N-Back Time ($p=0.010$) and N-Back % ($p=0.013$) test categories. Group C saw significant improvements only for steady state aerobic exercise treatment for the Stroop (i) test category ($p=0.033$) while other test categories trended toward significance (range of p values from 0.052 to 0.291).

The average response times and percentage of correct responses for the sleep deprived participants were compared to those of the control group participants using a two-way ANOVA. This comparison showed no significant differences between the control and sleep deprived groups ($p=0.110$) for any of the test categories. As a representative example comparison of control group to sleep deprived group, averages for the Stroop (n) test are shown in Figure 2.

**Discussion**

In our study, we analyzed the effects of a single bout of HIIT and steady state aerobic exercise on cognitive function in sleep deprived college students. There is evidence that there is an inverse relationship between sleep deprivation and cognitive function. In particular, there is evidence that supports that sleep deprived college students have a lower GPA than their non sleep deprived peers [5]. In addition to this, a lack of sleep negatively affects an individual behaviorally, psychologically, and physiologically [18]. There is some research supporting that exercise can combat the negative effects of sleep deprivation [3]. Using these previous studies as a guide, we wanted to see the relationship on how different types of exercise affects the cognitive function of sleep deprived college students. We found that a single bout of HIIT exercise and aerobic exercise improved attention, executive function, and working memory in sleep deprived students.

There have been studies looking at the relationship between exercise and cognitive function as well as studies looking at the relationship between sleep deprivation and cognitive performance. Our study is original in the fact that we looked at how different types of exercise (HIIT exercise, steady state aerobic exercise) affect cognitive function in sleep deprived college students. It provides evidence that randomly distributed subjects in three testing groups showed improvement in attention, executive function and working memory. Our data suggests that a single bout of high intensity interval or steady state aerobic exercise before a test can improve performance. This conclusion is drawn from our data showing statistically significant improvements in some test categories. Another implication of this data is that steady state aerobic exercise may be effective in improving more areas of cognitive function than HIIT exercise since steady state aerobic exercise led to significant improvements in more test categories than HIIT. While current research provides mechanisms for how exercise may increase cognitive performance via increased blood flow to the prefrontal cortex [3], there are no current suggestions for mechanisms that would lead to better cognitive performance after steady state aerobic exercise compared to HIIT. A possible reason for this difference may be greater exhaustion after HIIT exercise that may counteract some of the increased alertness resulting from increased blood flow. In addition, our data shows that individuals (whether or not they are sleep deprived) can gain the same positive effects from a single bout of HIIT or steady state aerobic exercise. This conclusion is drawn from the overall comparison of cognitive test results which showed no significant differences between control and sleep deprived participants. This then may indicate that an individual could see improvements in cognitive function after a single bout of exercise no matter whether they are sleep deprived or well-rested.

This study has two main limitations. The primary limitation of the study is the small sample size. Because there were only three subjects in each testing protocol (i.e. 3 sleep-deprived each of groups A, B, and C) and 9 sleep-deprived subjects overall, one subject, who may have been an outlier in a larger set of data, had the ability to skew the data averages since the small sample size leads to an increased statistical weight for each individual participant.

The second limitation comes from a factor inherent to the realm of cognitive testing, which is accounting for a learning effect. With cognitive tests such as the Stroop and N-Back tests, participants will improve over subsequent tests even without changes in treatment. In order to account for this, the study design incorporated a randomization process in which participants were assigned to different treatment groups, as seen in Table 1. While this does provide increased reliability for the statistical significance of the results, a learning effect may still have been able to skew the data. As shown in the comparison of group results, Group A showed significant improvement in all four test categories, while Groups B and C showed much smaller improvements, with only steady state aerobic exercise treatment leading to statistical significance in either one or two tests. As a result, larger average improvements due to the learning effect aligning with the treatment order (i.e. more experience with the tests coinciding with exercise treatment) in Group A may have pulled the overall average improvements up and led to significance where there may not have been had there not been a learning effect in Group A. To overcome this limitation in future studies, multiple pre-treatment test familiarization sessions should performed, which would then allow for a comparison to baseline test values once the learning effect has become insignificant in subsequent tests.

## Conclusion

A single bout of HIIT and steady state aerobic exercise in sleep deprived college students increased cognitive function in Stroop interference time. Steady state aerobic exercise exclusively improved the N-Back response time. Our data shows that steady state aerobic exercise before a test can improve attention, executive function and working memory. Our data also shows that HIIT before a test can improve attention and executive function. Using our evidence, we determined that there was no statistical significance between HIIT and steady state aerobic exercise to distinguish which form of exercise had a greater impact on cognitive function. Using our research model, further studies would be needed to see if HIIT exercise increases cognitive function in sleep deprived college students better than steady state aerobic exercise or is equally effective. Further study designs could increase their effectiveness in determining this as well as if exercise offsets the negative effects caused by sleep deprivation by comparing all sleep deprived participants to their own baseline results when well rested.

## Practical Implications

- College students who are sleep deprived should complete a single bout of HIIT or steady state aerobic exercise before attending class in order to improve test results and class performance.
- Positive effects of a single bout of HIIT or steady state aerobic exercise can benefit untrained individuals.
- Exercise duration does not have to be long in order to positively impact attention and short-term memory.

## Acknowledgments

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## Figures and Tables

**Exercise Order Assignment Protocol** Table 1

| | Group A | Group B | Group C |
|---|---|---|---|
| 1st Test | No Exercise | Aerobic Exercise | HIIT Exercise |
| 2nd Test | Aerobic Exercise | HIIT Exercise | No Exercise |
| 3rd Test | HIIT Exercise | No Exercise | Aerobic Exercise |

Figure 1

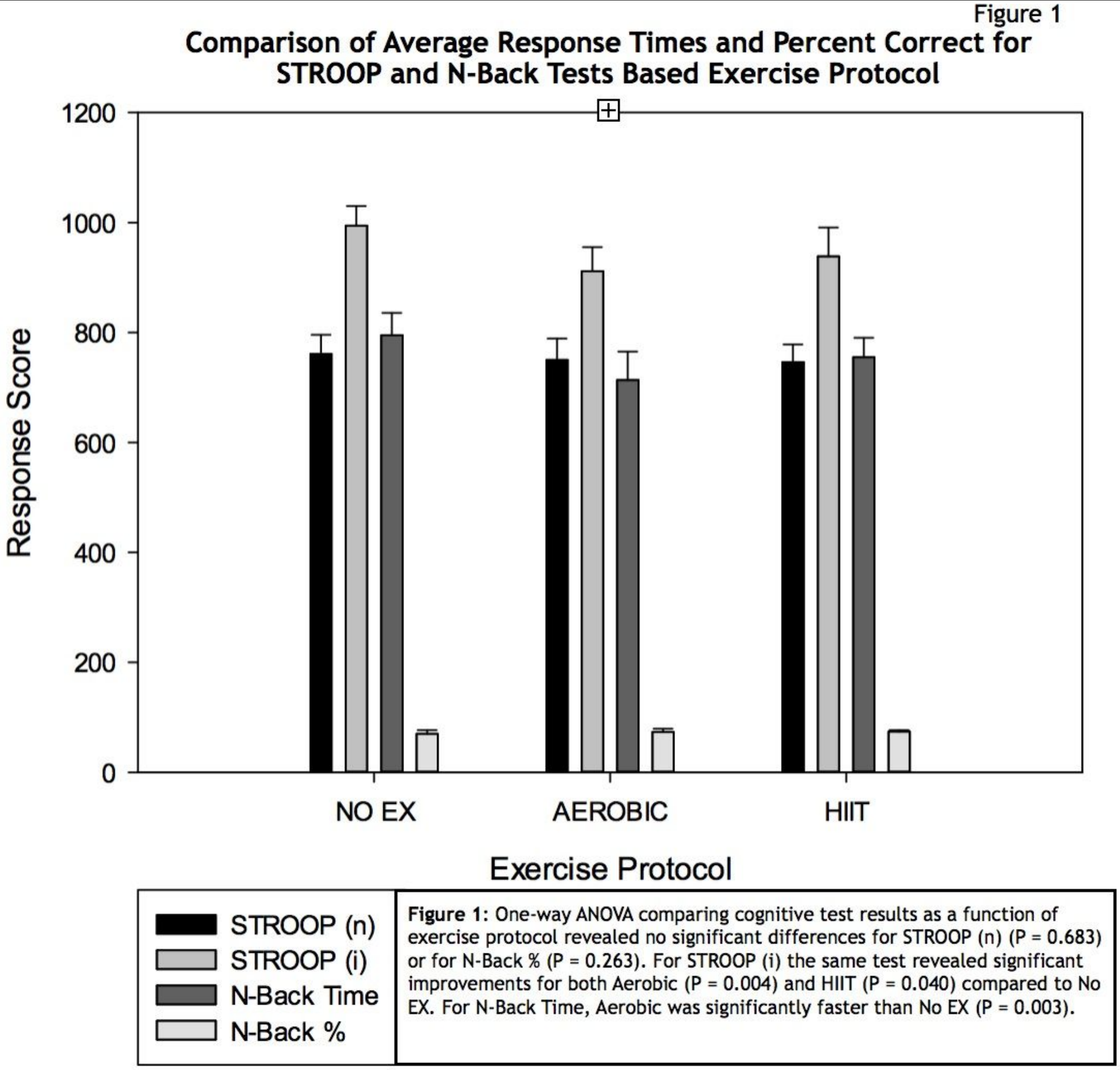


**Figure 1:** One-way ANOVA comparing cognitive test results as a function of exercise protocol revealed no significant differences for STROOP (n) ($P = 0.683$) or for N-Back % ($P = 0.263$). For STROOP (i) the same test revealed significant improvements for both Aerobic ($P = 0.004$) and HIIT ($P = 0.040$) compared to No EX. For N-Back Time, Aerobic was significantly faster than No EX ($P = 0.003$).

Figure 2

**Comparison of Average STROOP Normal Response Time for Sleep-Deprived and Control Groups Based on Exercise Protocol**

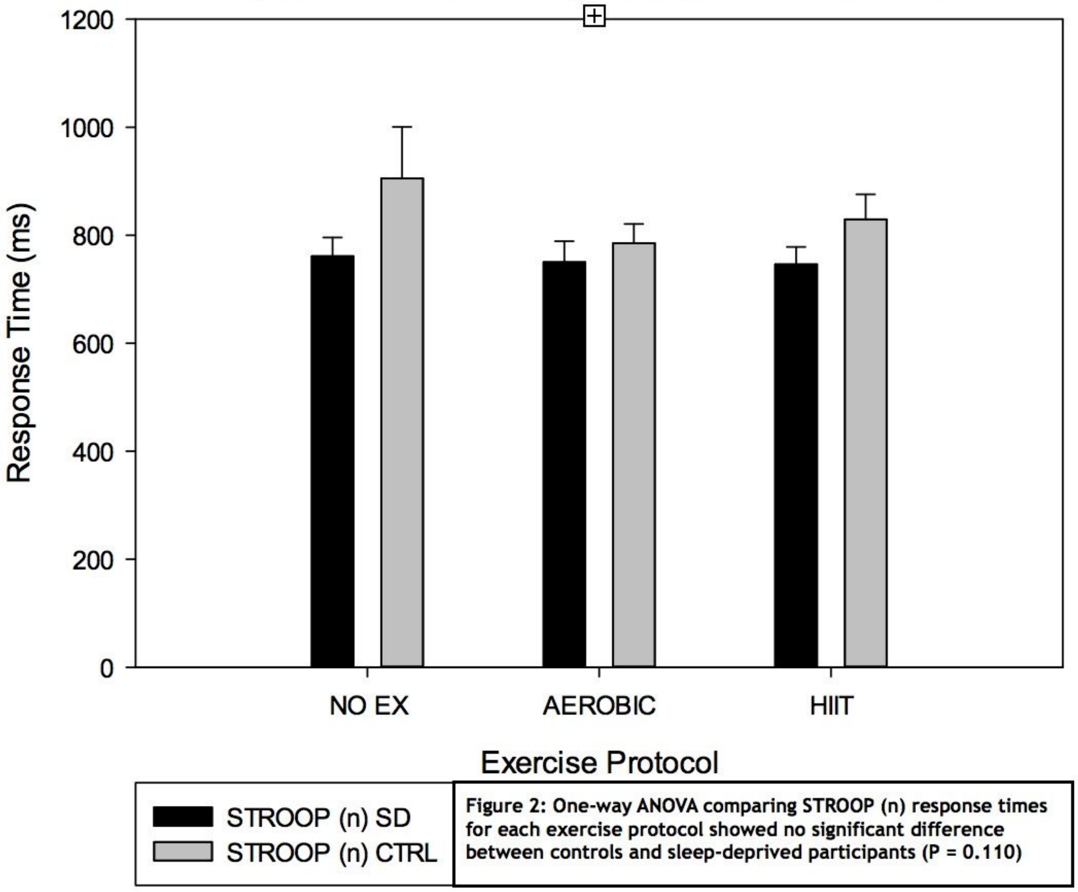


**Figure 2: One-way ANOVA comparing STROOP (n) response times for each exercise protocol showed no significant difference between controls and sleep-deprived participants (P = 0.110)**

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