The Effects of Acute Aerobic Exercise on Cognitive Function in Young Adults

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Abstract

Aerobic exercise has proven beneficial to physical health, and it has been suggested that aerobic exercise improves mental health as well, specifically cognitive function. However, few studies have looked at the effects of acute exercise on cognitive function in young adults. We examined Stroop completion time, as a measure of cognitive function, at rest, 30 seconds post-moderate exercise, 5 minutes post-moderate exercise, 30 seconds post-heavy exercise, and 5 minutes post-heavy exercise for 16 participants (mean= 20.875 years). In addition, we analyzed the relationship between cognitive function and two other fitness measures: Body-Mass-Index (BMI) and mean arterial blood pressure (MABP). Results indicated that, overall, Stroop completion time continued to improve at each post-exercise time point. Stroop completion times of overweight participants improved at a slower rate than normal-weight participants, with an exception at 30 seconds post-moderate exercise. Additionally, Stroop completion times of hypertensive participants improved at a faster rate than participants with normal blood pressure, with an exception at 30 seconds post-heavy exercise. Findings suggest a potential positive relationship between exercise and cognitive function as well as between fitness and cognitive function. These results could potentially have implications for advising young adults on the benefits of exercise on cognitive function.

Introduction

Physical exercise, specifically aerobic exercise, has been shown to promote several aspects of physical health. However, recent research has suggested it may also promote increased cognitive function (Ploughman 2008, Hillman et al 2008, Winter et al 2007). Cognitive function, for the purpose of this study, will be defined as the combination of cognitive flexibility, information processing speed, and selective attention while performing a task as efficiently and effectively as possible. Two mechanisms have been suggested to explain the effects of exercise on cognitive function: the oxygen hypothesis, which measures blood flow in certain regions in the brain, and the neurotrophic stimulation hypothesis, which suggests that neuromuscular activity promotes higher functioning brain centers (Spirduso 1980).

Various studies have found that long-term physical exercise may prevent decline of cognitive function in elderly populations and aging adults (van Uffelen 2008). However, varying results have been observed regarding acute exercise on cognitive function. Some studies suggest that acute exercise increases cognitive function (Pesce & Audiffren 2011, Pesce et al 2007), while others suggest that it may decrease or not alter cognitive function (McMorris et al 2009, Del Giorno et al 2010). This lack of consensus calls for further research regarding the effects of acute exercise on cognition. Furthermore, very few studies have looked at the effects of acute cardiovascular exercise on cognitive function in young adults.

During adolescence and throughout young adulthood, neural plasticity is at its peak. It is thought that exercise may capitalize on this critical period by stimulating the brain and promoting learning, memory and higher thinking (Hopkins et al 2011, Ploughman 2008). For the purpose of this study, young adulthood is defined as any age between 18 and 30 years of age.

The first objective of our study was to investigate changes in exercise intensity and the effects on cognitive function. Previous research has suggested that moderate physical activity is important for improving cognitive function in young adults (Ploughman 2008). Additionally, some studies suggest high intensity exercise elevates stress hormones, thus thought to have a lesser effect on improvement in cognitive function (Reynolds & Nicolson 2007); however, these results are controversial as other studies have found conflicting results (McMorris 2008, Winter et al 2006). Nonetheless, we expected that cognitive function will increase above baseline after both 30 seconds and 5 minutes (300 seconds) following moderate exercise. We expected that cognitive function will decline 30 seconds after heavy exercise but will increase above baseline 5 minutes (300 seconds) after heavy exercise.

Our second objective was to elucidate the effects of body mass index (BMI) on cognitive function. Previous research shows that, on average, people with higher BMI do worse on global cognitive function tests than people within a normal BMI ranges, at baseline (Gunstad et al 2007, Gunstad et al 2006, Elias et al 2003). Therefore, we expected that cognitive function of people with a BMI over 25 (a value defined as overweight) will increase at a lesser rate than people with a BMI in the normal weight range (18.5-24.9) after moderate exercise. We expected that cognitive function will decrease at a higher rate after heavy exercise for people with in the higher BMI group than for people with a normal weight BMI.

Finally, we assessed the effects of mean arterial blood pressure (MABP) on cognitive function. Prior research has found that hypertensive individuals performed worse than normotensive individuals on various cognitive function tests at baseline in both younger and older adults (Elias et al 2004, Elias et al 2003). However, a few studies suggest there is no correlation between blood pressure and cognitive function in young adults, but rather that there is a greater decline in cognitive function with increasing age for hypertensive adults (Bucur & Madden 2010). Nonetheless, we expected that participants with a MABP above 95.0 mmHg (mildly hypertensive) will experience an increase in cognitive function after moderate exercise at a lesser rate than participants with a MABP lower than 95.0 mmHg. We expected that participants with a MABP above 95.0 mmHg will experience a decrease in cognitive function after heavy exercise at a higher rate than participants with a MABP lower than 95.0 mmHg.

Methods

Subjects (n=16: 7 Females, 9 Males) were recruited from a convenience sample within the University of Wisconsin-Madison campus. Eligible participants were of at least 18 years of age (mean= 20.875 years, range= 19-23 years) and spoke English as their first language. Informed consent was obtained in written form prior to all measurements.

Exercise Protocol:

Subjects completed 2 separate bouts of aerobic exercise in a non-randomized order on a stationary bike. Before exercise began the subject completed a brief demographic survey, resting heart rate (HR) and blood pressure (BP) values were measured, and the subject took the first of 5 separate Stroop tests. After resting measures and tests were completed, subjects completed a moderate-intensity exercise. This exercise consisted of having the subject cycle until they reached a heart rate equal to 50% of their age-predicted max (220bpm-age). Once this HR was achieved, the subject continued to cycle for 3 minutes while maintaining the elevated HR. Thirty seconds after finishing the 3-minute bout of moderate exercise, HR and BP were measured, and the subject was administered a Stroop test. The subject then sat and rested for 5 minutes, after which HR and BP were measured, and then they took a separate Stroop test. Next, the subject was asked to complete a high-intensity exercise task. For the high-intensity exercise, subjects were instructed to achieve a HR equal to 75% of their age-predicted max, and then continued to cycle at this HR for 3 minutes. After high-intensity exercise was completed, the subject completed the above-mentioned 30 second and 5 minute post-exercise measurements and tests. See Figure 1 for a detailed chronological, graphical representation.

Standardized Questionnaire:

Prior to all physiological and cognitive measurements, participants completed a standardized questionnaire. From this, demographics regarding age, sex, height, weight, alcohol and caffeine consumption, and average weekly physical activity were obtained.

Physiological Measurements:

The following physiological variables were measured: Heart Rate (HR), Blood Pressure (BP), and Body Mass Index (BMI).

Heart rate was measured using Polar (model T31-Coded) heart rate monitors with wristwatches. The monitors were worn around the chest directly next to the skin, and the HR was monitored on the wristwatch display.

Blood pressure was measured using an automated BP device (ReliOn Blood Pressure Cuff, Model #144249001, made by Mabis Healthcare Inc.). From the systolic/diastolic values recorded from the automated device we then calculated Mean Arterial Blood Pressure (MABP) using the equation DP + 1/3PP, where PP (pulse pressure) was equal to systolic pressure-diastolic pressure (SP-DP).

Body-Mass-Index was calculated from the height and weight data collected from our self-reported participant survey. BMI= kg/m^2.

Cognitive Function Measurement:

Subjects completed 5 separate Stroop tests on a computer at the following time points: rest, 30 seconds after moderate exercise, 5 minutes after moderate exercise, 30 seconds after high-intensity exercise, and 5 minutes after high-intensity exercise. The tests were given in the same order to each subject, and the tests were randomly generated by the testing group prior to the start of the study. Each test consisted of 20 words (4 words, 5 rows). Participants had to indicate the ink color of the word (i.e. for RED written in a blue ink color, the correct answer is blue) and were instructed to get through the 20 words as quickly as possible. The time spent taking the test was recorded using a stopwatch, and a penalty of 1 second was incurred per mistake. The final score was equal to the sum of the time spent taking the test plus the added mistake time, if any.

Statistical Analysis:

Microsoft Excel was used to analyze the experimental results. All demographic information was analyzed and interpreted using descriptive statistics. Repeated-measures ANOVA assessed the changes in Stroop test completion time throughout the moderate and high-intensity exercise regimens. Mean Stroop score values were calculated to assess changes in Stroop test completion time between BMI groups (normal and overweight ($BMI \geq 25$)). Additionally, mean Stroop scores were used to examine changes in Stroop test completion time as a function of the change in mean arterial blood pressure throughout the exercise regimens.

Results

In general, Stroop completion time decreased as exercise intensity increased (see Table 1 and Fig. 2). Compared to rest, Stroop completion time significantly improved at 30 seconds post-moderate exercise (**$p < 0.0292$**), at 5 minutes post-moderate exercise (**$p < 0.0006$**), at 30 seconds post-heavy exercise (**$p < 0.0351$**), as well as at 5 minutes post-heavy exercise (**$p < 0.0023$**).

Additionally, Stroop completion time significantly improved between 30 seconds and 5 minutes post-heavy exercise (**$p<0.0001$**), however, no such significance was seen between 30 seconds and 5 minutes post-moderate exercise.

With the exception of 30 seconds post-moderate exercise, Stroop completion time improved at a slower rate for overweight (BMI≥ 25) participants than for normal (BMI= 18-24.9) participants (see Fig. 3).

With the exception of 30 seconds post-heavy exercise, hypertensive participants' Stroop completion time improved at each exercise intensity interval (See Fig. 4). A substantial improvement is seen at moderate 30 with a mean Stroop completion time of 11.9 sec.

Compared to non-caffeine consumers, caffeine consumption was correlated with improved Stroop completion time at rest (mean= 14.94 sec) and 30 seconds after moderate exercise (mean= 13.6 sec) (see Fig. 5). However, a decline in Stroop completion time for caffeine consumers was seen 5 minutes after moderate exercise (mean= 13.96) as well as 5 minutes after heavy exercise (mean= 12.68) compared to non-caffeine consumers (mean= 13.66 and mean= 12.22, respectively). No effect was seen after 30 seconds of heavy exercise between caffeine and non-caffeine consumers.

With the exception of 30 seconds after moderate exercise, female participants had faster Stroop completion times compared to male participants (see Fig. 6). On average, females were 1.38 seconds faster at rest; 1.21 seconds, 5 minutes after moderate exercise; 0.55 seconds, 30 seconds after heavy exercise; and, 0.51 seconds, 5 minutes after heavy exercise compared to male participants.

Discussion

The current study was the first study to look at the effects of acute exercise on cognitive function within the 18-30 age range. Specifically, we looked at moderate and heavy exercise intensity and its effects on Stroop completion time. We expected to see an increase in cognitive function after both bouts of moderate exercise. We also hypothesized that a decline in cognitive function would occur 30 seconds post-heavy exercise, but an increase in cognitive function would occur 300 seconds post-heavy exercise. Consistent with prior research (Ploughman 2008), our results indicate that Stroop completion time significantly improved with increasing exercise intensities as compared to rest (see Fig. 2). In accordance with our hypothesis, Stroop completion time improved from rest to moderate exercise intensity. However, contradictory to our hypothesis as well as to findings produced by Reynolds and Nicolson (2007), Stroop completion time also improved from rest to heavy exercise intensity. Our results also indicate that both the change in cognitive function between moderate 30 and moderate 300 as well as between heavy 30 and heavy 300 negate our hypotheses: Stroop completion time decreased between the moderate intensity intervals but increased between the heavy intensity intervals. This is consistent with studies conducted by McMorris (2008) and Winter *et al* (2006) whose research suggests that high levels of stress hormones after intense exercise further improves cognitive function. Such results in our study could be explained by a learned response. After being exposed to differing Stroop tests, one is likely to familiarize themselves with the style of the test allowing for faster processing speed, thus faster Stroop completion times.

The effects of overweight (BMI>25) versus normal (BMI= 18-24.9) BMI on cognitive function was also examined. According to our hypothesis, overweight participants would exhibit an improvement in Stroop completion time following bouts of moderate exercise at a slower rate than normal participants. In addition, Stroop completion time should have increased at a higher rate following heavy exercise in overweight participants. Contrary to our hypothesis, the overweight participants displayed decreased Stroop completion times at a slower rate with increasing exercise intensities than that of the normal group participants, with the exception of 30 seconds post-moderate exercise (See Fig 3). However, at every interval our results did not provide enough statistical power to determine if a significant difference existed between the normal and overweight participant Stroop completion times. This is contrary to research by Gunstad et al. (2007). Because BMI is not always an accurate measure of fitness as it does not account for muscle mass, some participants could have been misplaced into the overweight category. Implementing a more accurate fitness test could ensure appropriate group placement and more accurate and reliable results, which could account for the difference in results between our experiment and the Gunstad group.

The final aim of our study was to see if there was a difference in Stroop completion time between normotensive and hypertensive subjects. We defined hypertension as any subject, regardless of gender, with an MABP equal to or greater than 95mmHG, and we had 3 subjects meet this requirement. Regardless of tension status, both groups improved at each testing interval as compared to rest (see Fig. 4). Consistent with prior research, the normotensive group performed better than the hypertensive group at rest (Elias et al 2004, Elias et al 2003). However, there was a difference between the two groups' Stroop times obtained 30 seconds after the completion of moderate exercise: hypertensive participants produced a much faster completion time than the normotensive group. However, with such a small sample size (3), we cannot call this difference significant. We may have limited our ability to see statistically significant results by defining hypertension as equal to, or greater, than 95mmHG. Females, on average, have a lower MABP than males; therefore, more accurate results would have been obtained if we had made the cutoff for female subjects lower (e.g. 85mmHG). This would have resulted in a larger sample size, and we could have shown greater statistical significance.

Additional analyses of questionnaire data yielded mixed results regarding caffeine consumption (see Fig. 5). Initially, caffeine seemed to increase Stroop completion time; however, at subsequent time points the effects varied between slower Stroop completion times and no effect at all. Such results suggest that caffeine is likely not correlated with Stroop completion time after acute bouts of exercise. This, however, raises the question of whether or not exercise is the cause of a lack of correlation between caffeine and Stroop completion time. The amount of exercise prior to testing could be controlled to help eliminate another potential source of error. A follow up study with a larger sample population could look at the relationship between exercise and caffeine consumption on Stroop completion time.

The analysis between male and female participants indicates that females, on average, are faster at completing Stroop tests. However, at each subsequent time point the difference between male and female Stroop completion scores declined, with males showing a more profound improvement. The reasons for this are unknown; however it could be due to a difference in learned response or in the effects of exercise between males and females. Nonetheless, due to the overlap in male and female Stroop completion times, we are not able to determine significance.

Given the limited population size, our study did not have enough statistical power to determine the effects of nicotine and alcohol consumption on exercise or cognitive function. These variables could be examined in future studies by considering the amount consumed as well as consumption frequency and comparing these variables to Stroop completion time.

One limitation of this study is the assessment of cognitive function by using only the Stroop test. It is hard to tell if the improved (decreased) Stroop times were due to increase in brain function post-exercise or a learned response to the Stroop test. Even though five different Stroop tests were administered to minimize the effects of memory, participants could have become familiarized with the conventions of the tests. A learned response to the Stroop test would explain why participants improved after each exercise interval. One way to reduce the possibility of a learned response is to implement practice Stroop tests in order to acclimate participants to the test. Also, it could be possible that the number of errors increased after exercise, but the Stroop time decreased accordingly. Thus, number of errors and completion time could be considered independently in future tests.

Another source of error was that the population size was relatively small (n=16). This is especially relevant to the hypertensive and overweight groups that have population sizes of 3 and 5, respectively. With a smaller population size, outliers become more relevant and will have a greater effect on results and statistical significance than in a large population size.

Furthermore, physically fit individuals may not be affected as much as overweight individuals since the exercise periods are relatively short. Our study attempted to account for this discrepancy by standardizing target heart rate and exercise time, but physically fit subjects would return to baseline faster than those who do not exercise frequently. In addition, BMI is not an accurate predictor of fitness level because it does not account for muscle mass or body fat percentage.

Future studies should focus on using multiple cognitive function tests to elucidate the effects of acute exercise on cognitive function. Multiple cognitive function tests would theoretically reduce the learned response of participants and thus yield the most accurate results.

Blood assays for biological factors that have been correlated with altering brain function and/or fitness, such as brain-derived neurotrophic factor (BDNF), epinephrine, and norepinehrine, could also further validate the study. Additionally, various types of exercise could be examined to determine which exercise type has the most beneficial impact on cognitive function in young adults.

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Tables and Figures

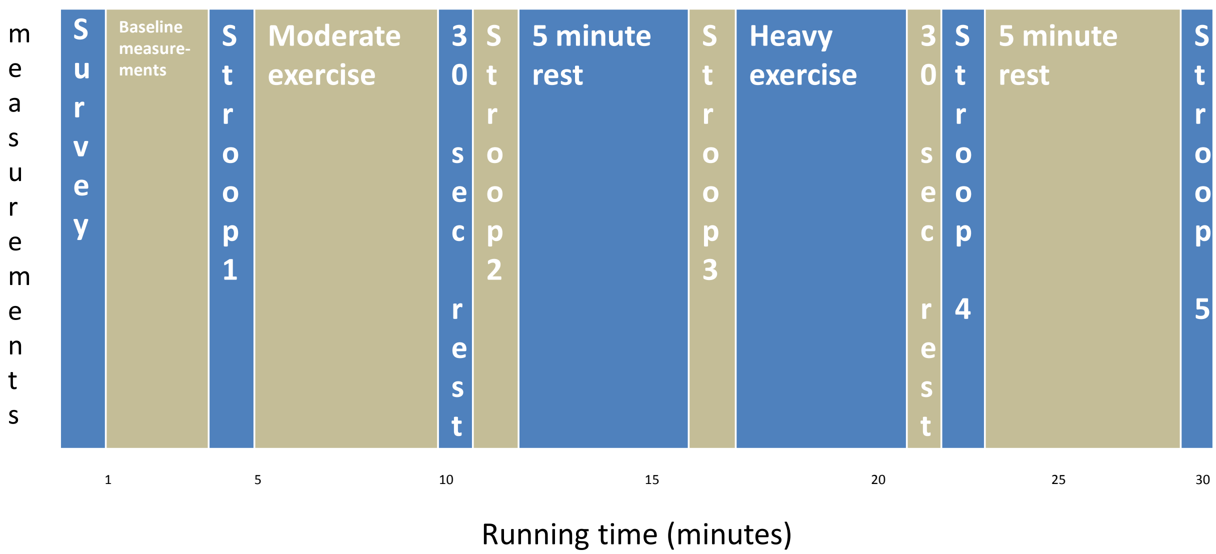

Figure 1: Sequence of experimental events including time intervals.

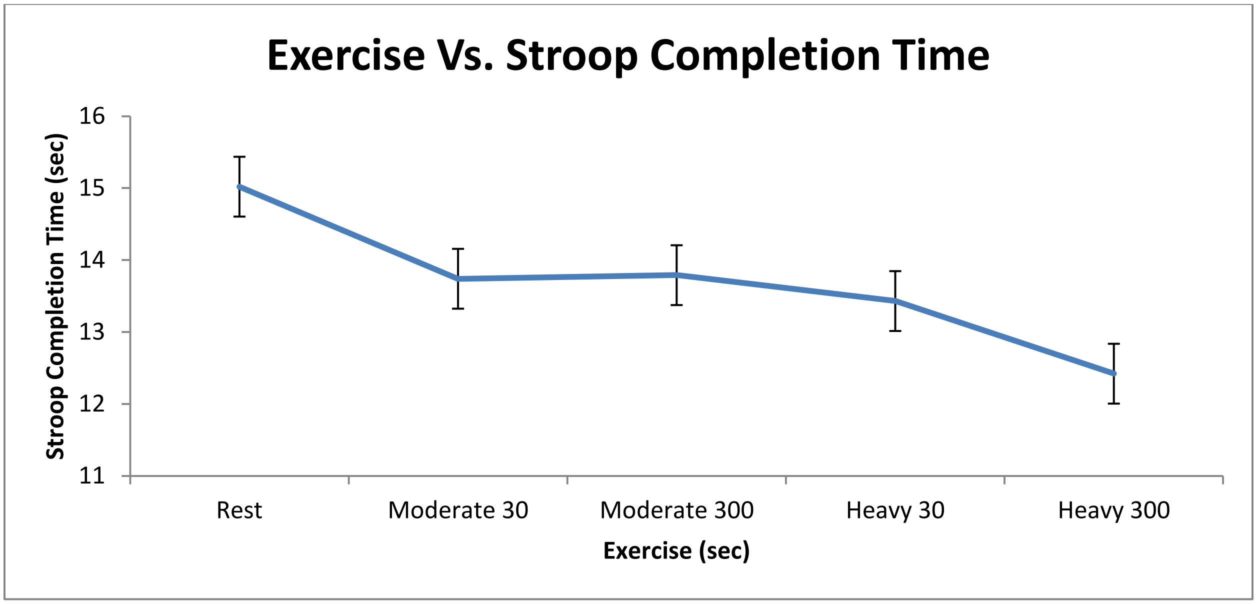

Figure 2: The average Stroop completion time at each post-exercise interval.

Table 1: Pairwise Comparison of Stroop Completion Times Between and Within Exercise Intensity Groups.	
Rest vs. Moderate 30	**p< 0.0292***
Rest vs. Moderate 300	**p< 0.0006****
Rest vs. Heavy 30	**p< 0.0351***
Rest vs. Heavy 300	**p< 0.0023***
Moderate 30 vs. Moderate 300	**p< 0.9138**
Heavy 30 vs. Heavy 300	**p< 0.0001****

*= **p< 0.05**, **= **p< 0.001**

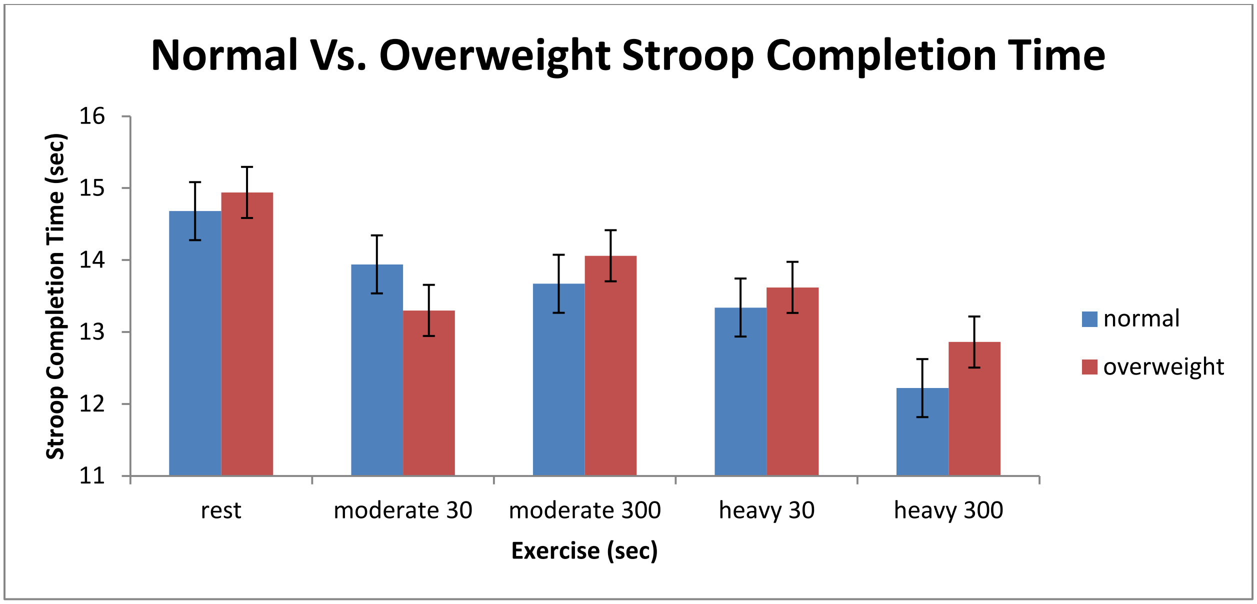

Figure 3: The average Stroop completion time between overweight (n= 5) and normal participants (n= 11).

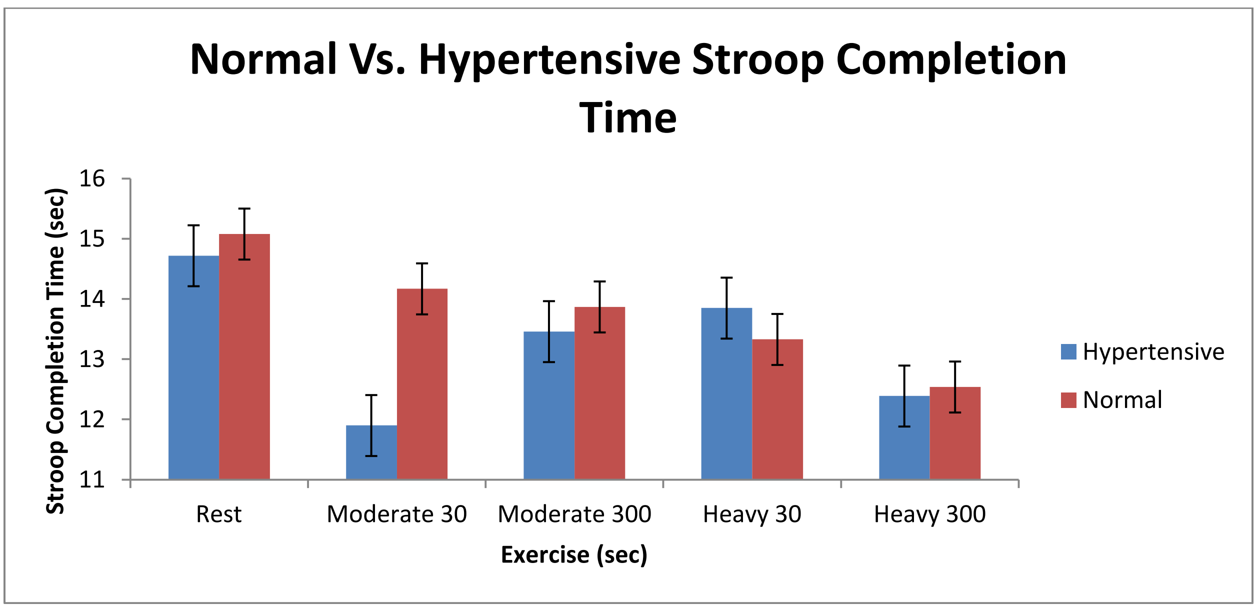

Figure 4: The average Stroop completion time between hypertensive (n=3) and normal participants (n=13).

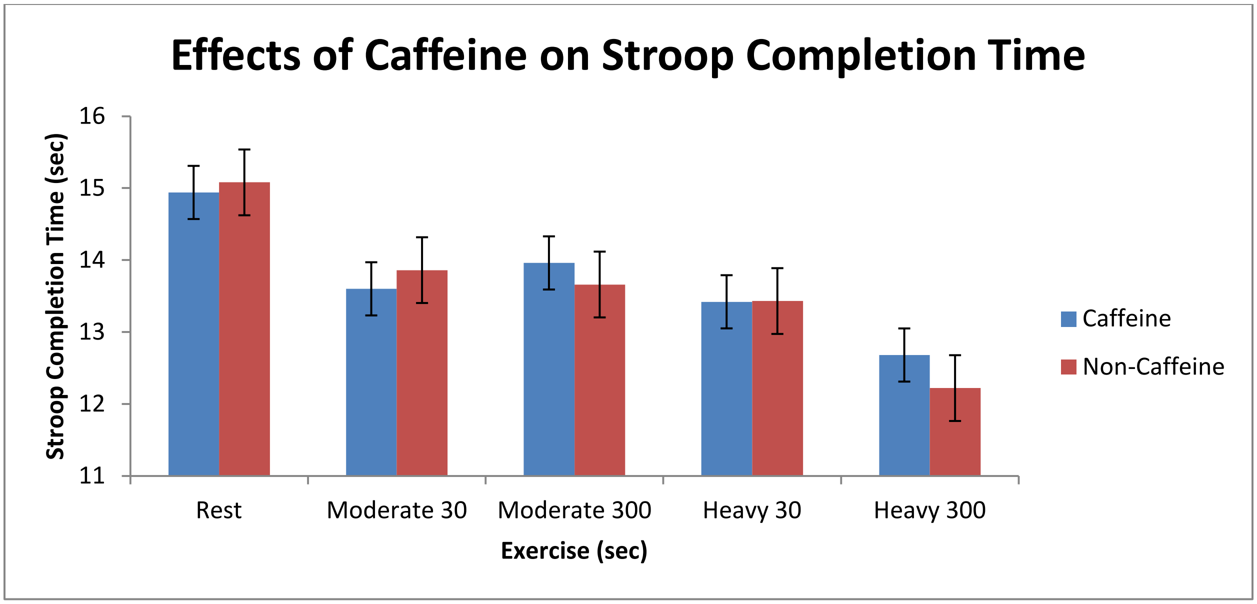

Figure 5: The effects of caffeine (n=7) on average Stroop completion time.

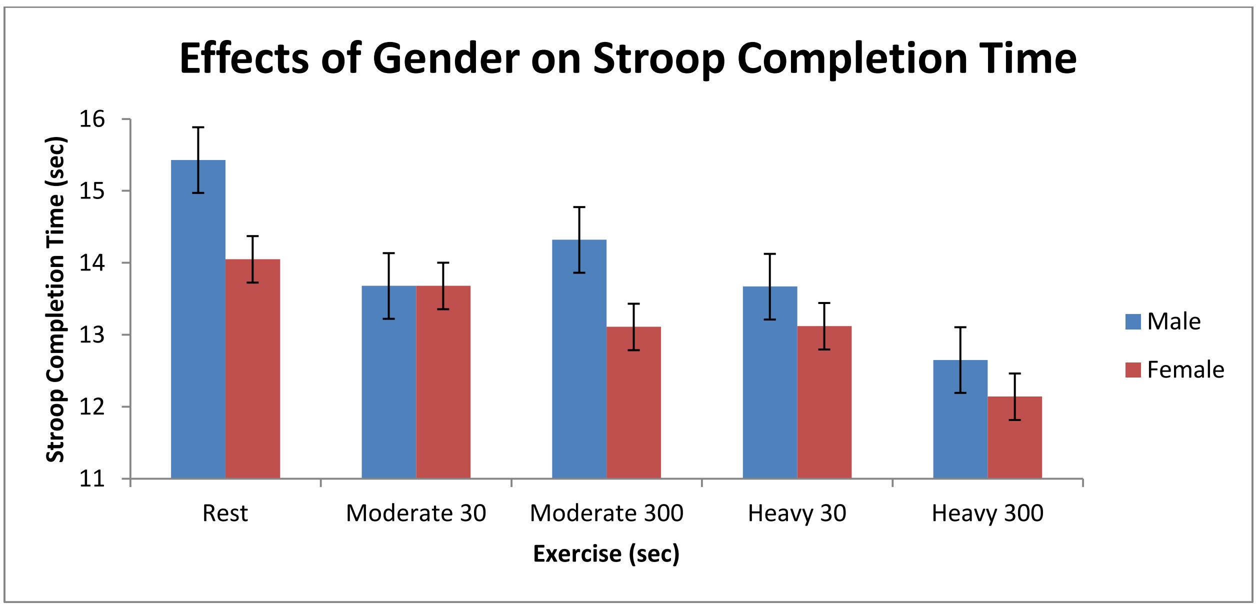

Figure 6: The effects of gender (Female= 7, Male= 9) on average Stroop completion time.

Appendix

a) Physiology 435 Survey

Effects of Exercise on Cognitive Function Survey

Age:

Gender: **M / F**

Height:

Weight:

Regular tobacco smoker?: **Y / N**

Did you consume caffeine this morning: **Y / N**

On average, how many alcoholic drinks do you consume per week?:

Rate your level of average weekly physical activity (circle one):

0 **0 hours of physical activity**

1 **1-2 hours per week**

2 **3-5 hours per week**

3 **5-7 hours per week**

4 **7-10 hours per week**

5 **10+ hours per week**

Preferred mode of exercise/physical activity (circle top choices):

Running **Biking** **Swimming** **Skiing**

Strength-training **Team sports** **Other**