The Effects of Aerobic Exercise on Cognitive Flexibility

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Abstract:

This experiment tested the hypothesis that that the Stroop test would show no improvement after normalization because of the intense cognitive function required to complete the task. We also predicted that one episode of exercise would not prompt a measurable difference in overall performance. Twenty five individuals between the ages of 20-23 were tested for resting blood pressure, heart rate and a Stroop test. Then, subjects ran up and down stairs to increase their heart rate to ~140 bpm. After exercise, each subject was then tested again for heart rate, blood pressure and the Stroop test. Heart rate and blood pressure were used to monitor the intensity of exercise. The Stroop test was used to monitor cognitive flexibility. Our results indicated that although no significant correlation between heart rate, blood pressure, and Stroop test score could be determined, there was an overall increase in Stroop scores after exercise. This project is physiologically significant in finding whether cognitive flexibility and performance can be altered with a healthy lifestyle.

Introduction:

Exercise has been implicated in many different tests of brain function. In a recent study moderate intensity aerobic exercise (defined by 70-80% of maximal heart rate) has been shown to improve working memory (Kavussanu 2013). The correlation between exercise and cognitive function has been investigated in many studies over the past thirty years and collectively they indicate an increase in cognitive function following exercise (Etnier 1997, Lambourne 2010). One recent area of interest is cognitive flexibility or the ability to construct and modify responses based upon information (Deak 2003). In the ever-evolving world in which we live, cognitive flexibility and the ability to quickly synthesize information seems more useful than routine memorization. One way to measure cognitive flexibility is the Stroop test. In performing this task, the name of a color is printed in a color not denoted by the name. The Stroop effect demonstrates the interference associated with reaction time and thus has been validated as a test of cognitive flexibility (MacLeod 1991). In older, sedentary adults who were put on a three-month exercise program, cognitive flexibility, as measured by the Stroop test, was shown to increase (Bherer 2011). Despite the fact age has been proven not to be an indicator of Stroop test success, this effect has not been tested in younger adults leading relatively active lives (in comparison to older inactive adults previously tested) (De Meersman 1998). Recently, acute exercise has been shown to improve cognitive flexibility on the Stroop test in young, 19-24 years of age, Japanese adults by activating the dorsolateral, prefrontal cortex (Yanagiawa 2010). Our study seeks to demonstrate the effect of short-term aerobic exercise on cognitive flexibility in young adults. Specifically, will approximately five minutes of aerobic exercise on a staircase improve cognitive flexibility as measured by the Stroop task. Through literature review, aerobic exercise was found to improve cognitive function. By reviewing previous experiments, we noticed mainly memory was tested. We decided to expand this to include cognitive flexibility. Researching the Stroop task, it was determined to meet our criteria of testing cognitive flexibility. Exercise on a staircase was limited to approximately 5 minutes due to participant time constraints.

The three physiological measurements required for this experiment include, heart rate (140-160 bpm pick specific point), blood pressure, and the Stroop Test. We continued monitoring blood pressure and heart rate throughout the test to ensure a constant level of aerobic activity was kept. In order to take into account improvement on the test simply due to taking the test more than once, we normalized Stroop test performance (see methods). This was done during our feasibility studies where we tested all five group members without exercise using the Stroop scoring shown below. This normalization was taken into account (subtracted from observed improvement; if any) following the post exercise Stroop test. During our feasibility studies we used the same Stroop word, color, and color-word tests that we will be using during the actual assessment. As previously stated, we took the average improvement (calculated in our feasibility studies) and subtracted it from the performance score values. We used a staircase to achieve an elevated heart rate of 140 or above.

By application of the Stroop test before and after exercise, we were able to see if short-term moderate exercise is related to a change in cognitive flexibility. Each group was be randomized to simulate the general population. The pre-exercise Stroop test functioned as the control to compare the post- exercise scores. Each participant functioned as their own control by comparing pre-exercise to post-exercise. Since it was likely that performing the test more than once resulted in improvement, this average improvement was normalized to account for the improvement of the post- exercise test.

Below is the formula commonly used and the one that we utilized to calculate interference from the Stroop test (Al-Ghatani 2010):

$$(C \times W) -\div (C+W) = CW' \text{ (Expected score)}$$

$$CW - CW' = \text{Interference}$$

This interference score was compared between pre- and post-exercise test to determine if short-term aerobic exercise is correlated with an increase in cognitive flexibility. Our methods are summarized in the following figure (Figure 1).

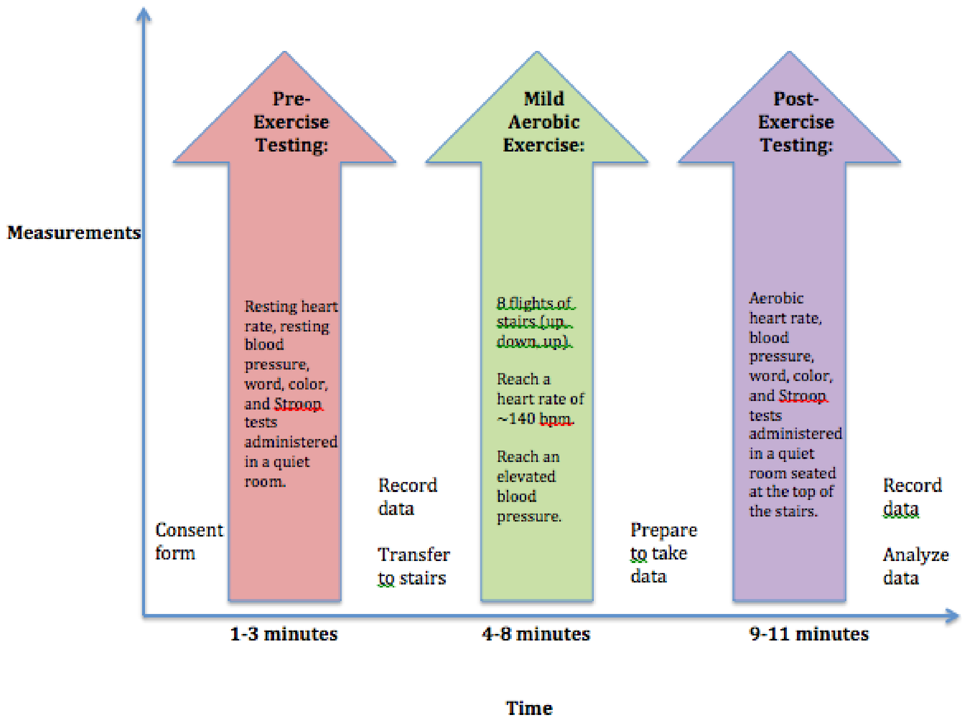

Figure 1: This figure describes our approach to collecting data. Both pre-exercise and post- exercise testing were measured.

We hypothesized that the Stroop test would show no improvement after normalization because of the intense cognitive function required to complete the task. We also predicted that one episode of exercise would not prompt a measurable difference in overall performance.

Materials:

- Heart rate/ Blood pressure wrist monitor
- Stopwatch
- Stroop Test booklet including pre/post exercise tests (Word, Color, Stroop)
- Consent Forms

Methods:

After signing a consent form, each participant had his or her resting blood pressure and heart rate measured by an automatic blood pressure wrist cuff. Each participant then performed word exercises. The first test consisted of a list of 110 black print names of colors. The second test consisted of 110 blocks of colors (red, yellow, purple, green, black, orange, blue, brown). The third test was a traditional Stroop test in which names of colors are typed in a different color font than the color the word represents. Each participant had 30 seconds in a quiet room to correctly articulate as many items as possible on each list, saying the word, color, and word's font color, respectively.

After all pre-exercise tests have been performed, each person participated in mild aerobic exercise consisting of running 8 flights of stairs 3 times (up, down, up). After exercise, heart rate and blood pressure was measured again. After the desired heart rate of 70% of maximum aerobic heart rate (~140 bpm; (220- age) x 0.70) and elevated blood pressure were reached, each participant immediately repeated the word, color, and Stroop tests with a randomized order of items different from the pre-exercise tests.

The pre- and post exercise test scores were then calculated for interference using the equations:

$$(C \times W) -\div (C+W) = CW' \text{ (Expected score)}$$
$$CW - CW' = \text{Interference}$$

Where C is the score of correctly articulated colors of the color block test, W is the score of correctly articulated words of the black text test, and CW is the score of correctly articulated colors of the Stroop test. The interference is the difference between the actual performance score on the Stroop test and the expected score.

A predetermined average improvement was successfully determined by having 5 participants with no prior exposure take all word tests corresponding to the pre-exercise tests. After a period of 5 minutes rest without exercise, the same participants took the word tests corresponding to the post exercise tests. These scores were used only to find improvement from Stroop test exposure, without looking at the effects of exercise. The interference for each set of tests was then determined. This value was averaged between all 5 participants and then subtracted from the experimental values to normalize improvement solely from exposure to the tests. The improvement score from doing the Stroop test more than once was 3 words per 30 seconds.

The experimental interference scores were then normalized by subtracting the pre-determined average improvement gained from performing the test more than once (3 words per 30 seconds). By subtracting the average improvement from each interference score, a final normalized improvement score was determined.

Data was then analyzed by averaging normalized scores to determine how exercise affects cognitive flexibility. Heart rate and blood pressure measurements were also normalized by dividing the difference between final and initial values by the initial value in the following equation: $(x_f - x_i)/x_i$. We found correlation values between our 3 measurements; blood pressure, heart rate, and Stroop test score. P-values were calculated between variables to determine if our data is significant. This data analysis can be seen below.

Results:

Heart Rate

Heart rate was primarily used to monitor the intensity of the exercise. The resting heart rate average was 75.8 beats per minute and the average heart rate after exercise was 141.2 beats per minute. There was a -0.144 correlation observed between change in heart rate compared to the Stroop test improvement for each subject (See Figure 2). A p-value of 0.996 was also observed.

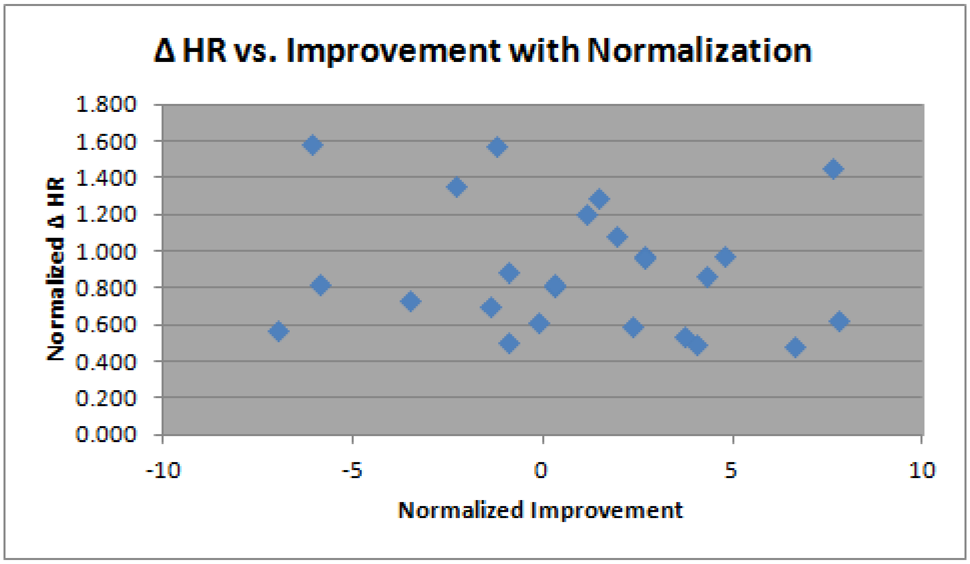

Figure 2: Graph displays the change in Heart Rate compared to the Stroop Test Improvement for each subject. The observed correlation is -0.144 and the observed p-value is 0.996121.

Blood Pressure

Blood pressure was also used to monitor the intensity of the exercise. There was a 0.144 correlation observed between change in systolic blood pressure compared to the Stroop test improvement for each subject (See Figure 3). A p-value of 0.405 was observed. There was also a -0.002 correlation observed between change in diastolic blood pressure compared to the Stroop test improvement for each subject (See Figure 4) with a p-value of 0.316.

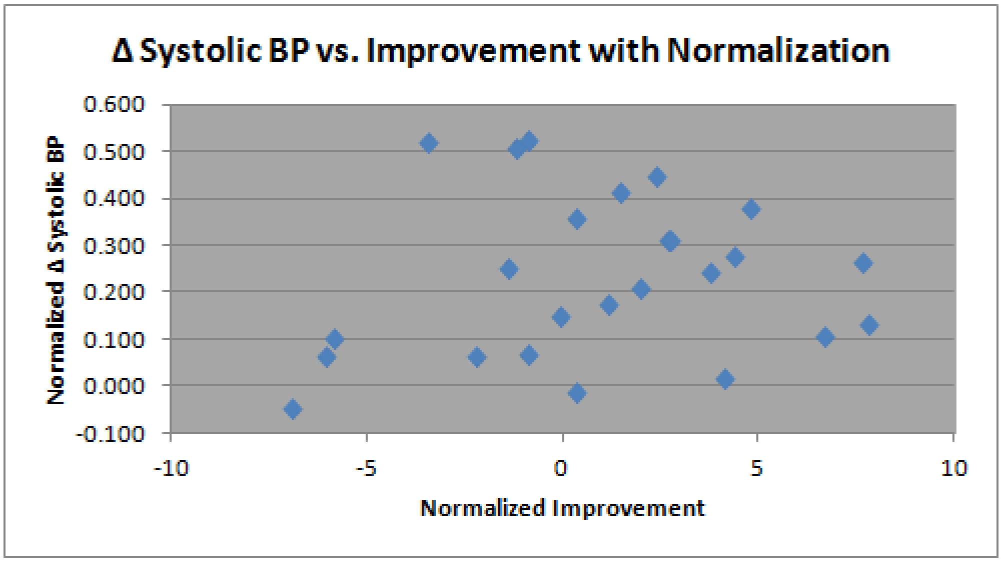

Figure 3: Graph displays the change in Systolic Blood Pressure compared to the Stroop Test Improvement for each subject. The observed correlation is 0.144 and the observed p-value is 0.405374537.

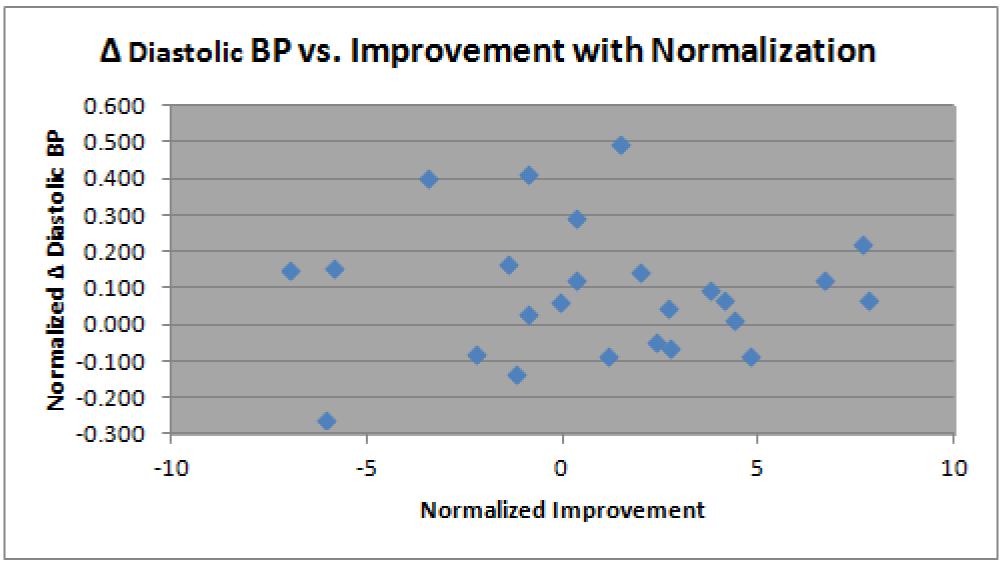

Figure 4: Graph displays the change in Diastolic Blood Pressure compared to the Stroop Test Improvement for each subject. The observed correlation is -0.002 and the observed p-value is 0.315983378.

Interference

Interference score was calculated for each participant before and after exercise. The scores were then compared to determine the effect of aerobic exercise. The average interference before was 6.349 and the average interference after was 10.254. There was a correlation of

0.727 between the initial and final interferences per participant (See Figure 5) with a p-value of 0.0135.

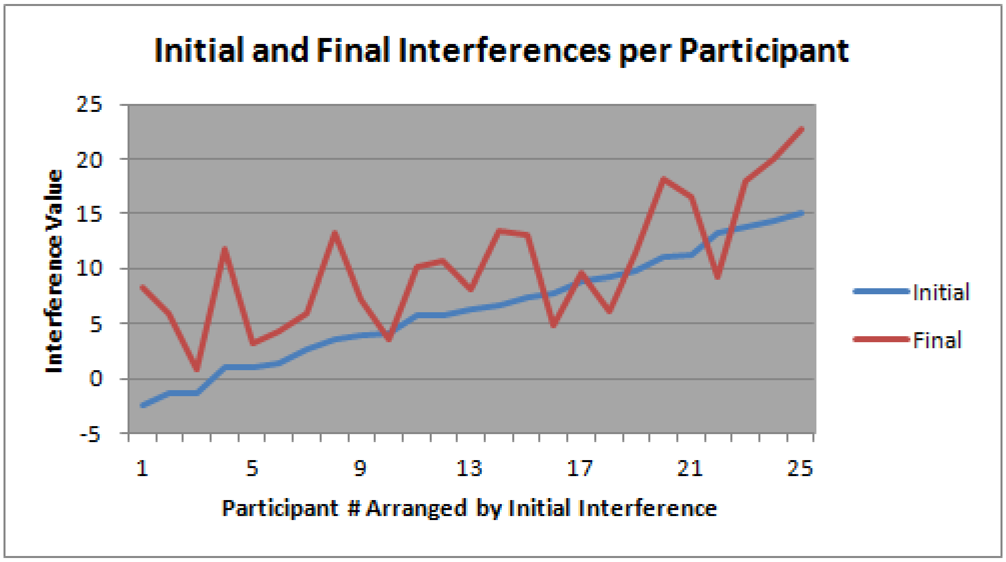

Figure 5: Graph displays the Initial Interference compared to the Final Interference for each subject. The observed correlation is 0.727 and the observed p-value is 0.013540741.

Stroop

The Stroop test was used to determine cognitive flexibility. There was a 0.571 correlation observed between the average initial actual and expected stroop scores (See figures 6 & 7) and a p-value of 0.000155. There was also a 0.572 correlation observed between the average final actual and expected stroop scores (See figures 6 & 7) with a p-value of 8.965×10^{-8}.

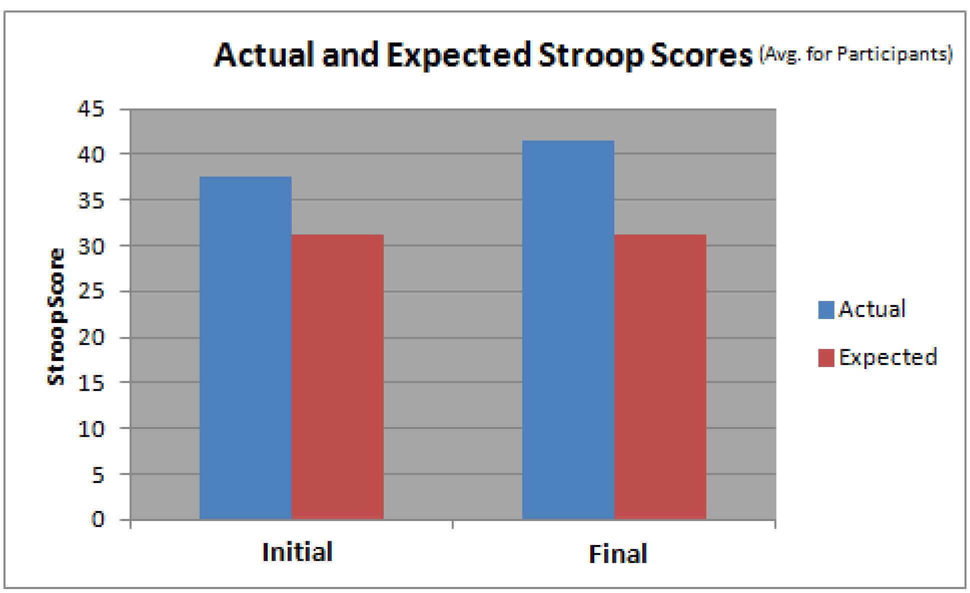

Figure 6: Graph displays the initial average actual and expected stroop scores compared to the Final average actual and expected stroop scores. The observed correlation for the initial is 0.571 and the initial p-value is 0.000155. The observed correlation for the final is 0.572 and the final p-value is 8.96531E-08

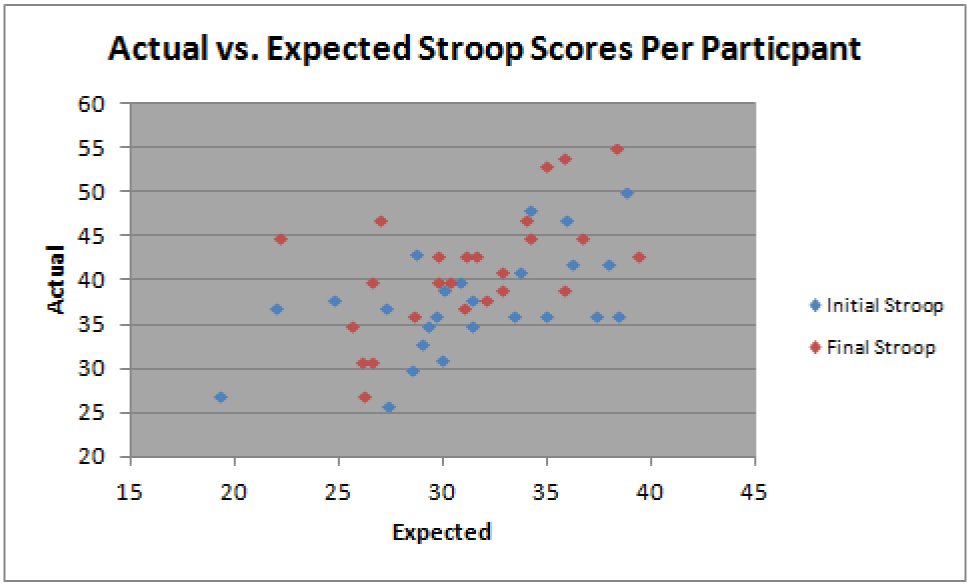

Figure 7: Graph displays the actual initial and final stroop scores compared to the expected initial and final stroop scores for each participant. The observed correlation for the initial is 0.571 and the initial p-value is 0.000155. The observed correlation for the final is 0.572 and the final p-value is 8.96531E-08

Discussion:

Our original experiment hypothesized that participants would not show an improvement in Stroop test performance after one short period of exercise due to the intense demands of the test on concentration. Heart rate and blood pressure were measured before and after exercise in addition to Stroop test performance to determine if aerobic exercise had been achieved. Our data showed that although heart rate was elevated in all participants, there was not significant relationship between change in heart rate and normalized change in Stroop test score. The p-value of 0.996 and correlation of -0.144 confirms that a change in heart rate had no effect on Stroop performance. There was also no significant relationship between systolic or diastolic blood pressure, as shown by p-values of 0.4054 and 0.316 respectively. These results can be seen in Figures 2, 3 and 4. This lack of a relationship does not have much effect on our hypothesis, as we were looking merely if Stroop test scores improved with aerobic exercise, and not at their relationship with specific heart rates. Average heart rate doubled during our experiment, indicating that participants achieved aerobic exercise.

Even though there was no significant correlation between heart rate, blood pressure, and Stroop test score, there was an overall increase in Stroop scores after exercise. Interference scores, calculated by subtracting the expected Stroop score from the actual Stroop score, were higher overall after exercise than the initial interference score, as shown in Figure 5. A p-value of 0.0135 confirms that there is a significant difference between final and initial interference scores. However, some participants improved their scores more than others. Those that had higher initial scores also had higher final scores, but did not necessarily improve their scores more than others. In addition, some participants did worse after exercise. Participants did better on average than the expected value both before and after exercise, and actual scores improved after exercise, even though the expected score for participants was about the same both before and after exercise (Figures 6 and 7). In our analysis of the data, we also normalized the scores to account for improvement from taking more than one Stroop test. When this normalization is taken into account, there is less improvement after exercise. Our data shows that over half of participants improved their scores even with normalization, but the proportion whose scores worsened is greater. The trend of the actual scores being higher than the predicted scores can be accounted for by the small subset of the population in the class. All participants were young, relatively healthy, college students with similar intellectual abilities. By having a more diverse population, it would be more representative of the general population and have more applicable results. By using a more varied sample of participants, we would hope for a wider range of scores and more pronounced improvement after exercise. We could also make better distinctions between the results of each category (gender, age, handedness, etc.).

There were several problems we encountered while performing our study that could have had an effect on the results. Due to the desire to measure performance on the Stroop test while heart rate and blood pressure were still elevated, the participants often did not have time to catch their breath before beginning to take the Stroop test. Since this test involved speaking out loud, several participants felt that they could have improved their performance if they had been given time to rest, instead of having to speak while still catching their breath. However, the participants were given the word only and color only tests first, when they were most out of breath, and the effect of this on their interference scores would have been greater than on their final Stroop score. To control for this in the future, an online Stroop test could be done, where participants must click the right answer as opposed to saying it out loud.

Although we tried to be as consistent as possible taking all of our measurements, there were still some problems associated with using an automatic blood pressure cuff instead of measuring blood pressure manually. There were several reasons for doing this, including a lack of experience on the part of the experimenters in correctly measuring blood pressure, and because by shortening the time involved with taking vital measurements, it was more likely that the subject's vitals were still elevated when they took the Stroop test. The same automatic blood pressure cuff was used for most of our measurements, but occasionally another was used that may have given a higher or lower reading. In addition, the normal blood pressure cuff had a tendency to report a higher value than expected. Due to the fact that we were measuring only for elevation and not looking for a specific value, this probably didn't have a significant effect on our final results.

Finally, although we controlled for improvement caused by performing a Stroop test multiple times in a short time span, there were several participants who had prior exposure to the Stroop test as a part of their own research. These participants could have performed better simply because of their familiarity with the test. However, since each participant was used as their own control, their scores were not excluded.

As with all exercise research studies, future research could be done on the difference in effects of short-term aerobic exercise and long-term physical fitness. We hypothesized that one session of exercise would not improve Stroop test performance, but it is possible that regular exercise and overall health improves scores. Further studies will continue to test the relationship between exercise and brain function, and it could be valuable to use the Stroop test to test mental function.

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Appendix:

	Number of Subjects	Mean Normalized Improvement	+/- Standard Deviation
Male	15	0.547	3.835
Female	10	1.441	4
Left Handed	3	1.647	1.241
Right Handed	22	0.804	4.15
Age 20	7	-0.092	4.522
Age 21	9	0.73	3.81
Age 22	7	2.425	3.44
Age 23	2	-0.14	1.265