Moderate Aerobic Exercise has an Inconclusive Effect on Fine Motor Control

Nicole Cancel, Mike Fischer, Lea Gulotta, JiYoon Koo, and Samantha McKittrick
Lab 603, Group 5

Terms

Aerobic
Sympathetic nervous system
Exercise
Fine motor skills/fine motor control
Heart rate
Mean arterial blood pressure

Abstract

Fine motor control involves the coordination of many different physiological systems to produce precise movements. The central nervous system, peripheral nerves, muscles, and blood vessels all have an active role in determining an individual's fine motor skills. Acute moderate exercise may stimulate the sympathetic nervous system, which causes skeletal muscle vasodilation and increased cardiac output, allowing more blood to perfuse the muscles. This effect, accompanied by an increase in cortical blood flow, was hypothesized to lead to an increase in fine motor skills, as measured by the ability to perform a standard pegboard assessment. Because there are many factors that may influence fine motor control, we focused on measuring noninvasive cortical blood flow. While the experimental subjects exhibited a change in fine motor skills after exercise as compared to before exercise, control subjects also showed the same improvement, suggesting that the improvement could have been attributed to a learned response. Due to a small sample size and insignificant statistic analysis, we were unable to draw definite conclusions about the effects of moderate exercise on fine motor control. However, there are revisions that could be made to the experimental design to further analyze the effects of moderate aerobic exercise on fine motor control that we believe could lead to the initial hypothesized results.

Introduction

Fine motor control is the coordination of muscles, bones, and nerves to produce small, precise movements, according to the U.S. National Library of Medicine. A common example of this would be picking up a pencil and writing in a controlled fashion. The brain, spinal cord, peripheral nerves, muscles, and joints all play a role in effective motor control (Mannheim 2013). Fine motor control is highly valuable in the specialized world that humans live in today. WebMD stresses the importance of children reaching fine motor developmental milestones to enable normal functioning such as drawing, eating, and manipulating small objects. We have, however, found little information regarding what exactly affects fine motor skills in developed individuals. This is one reason why exploring fine motor skill function and moderate exercise is important.

Another quality humans possess is the ability to adapt to environmental stress. This is done in part by activation of the sympathetic nervous system (SNS), which is a part of the autonomic nervous system (Parrott-Sheffer 2013). The sympathetic nervous system uses norepinephrine, cortisol, and epinephrine to induce a response in target tissues. Norepinephrine stimulation via the SNS is known to cause increased heart rate, increased cardiac output, skeletal muscle vasodilation, gastrointestinal vasoconstriction, bronchial dilation, among other physiological responses (Parrott-Sheffer 2013). According to a Mueller 2007 study, there is often disagreement about the extent to which the sympathetic nervous system is activated by different stressors. It is known that both acute and chronic exercise have significant effects on SNS activity (Mueller 2007). While it is true that the significance of the physiological responses induced by the SNS vary depending on age, gender, previous fitness levels, and the degree of adiposity of the subject, it is nonetheless clear that moderate physical activity does cause activation of the sympathetic nervous system in humans.

One of many of the physiological effects the SNS stimulates in the body is skeletal muscle vasodilation and increased cardiac output (Parrott-Sheffer 2013). This widening of the blood vessels decreases the resistance across the vessels, allowing for greater blood flow to permeate the muscle tissue. Increased cardiac output means that the heart is pumping more blood per unit time as compared to when the sympathetic nervous system is not activated. This increased blood flow accompanied by a decrease in total peripheral resistance of the blood vessels means that it is possible that more blood is reaching the skeletal muscles in the appendages. This would increase the ability to perform small, precise tasks with the fingers.

In addition to the effects on the skeletal muscles, the sympathetic nervous system can also exert an effect on the brain and the neurons of the motor cortex. Activation of the SNS causes an increase in cortical blood flow, which can lead to faster reaction times (Ozyemisci-Taskiran et al. 2008). In addition, according to a literature review conducted by Patrick J. Smith et al., several studies using randomized, controlled trials supported the idea that aerobic exercise training can lead to modest improvements in attention and processing speed (2010). This would mean that exercise would induce an improvement in the cognitive aspects of performing a fine motor skills assessment, as well as the physical aspects. Based on this rationale, we predict an episode of moderate aerobic physical exercise will decrease the time and increase the accuracy with which a subject performs a fine motor task, as compared to their performance before exercising. We recognize that there are numerous factors and complexities that influence fine motor control, but based on the scope of our experiment and the equipment available to us, we specifically focused on blood flow as a determinant of fine motor control.

To test this hypothesis, each subject’s resting heart rate was measured using a pulse oximeter. This was used as a monitor to ensure that subjects reached a level of physical exertion sufficient to induce the sympathetic nervous response. Target heart rate was 60% of each subject's age-predicted heart rate maximum. We also manually measured subjects' resting systolic and diastolic blood pressure using a blood pressure cuff and stethoscope. We used these measurements to calculate mean arterial blood pressure. All subjects performed a fine motor skill assessment by placing pegs into the holes of a pegboard as quickly as possible, with the score being the number of pegs placed in 30 seconds. Subjects were then asked to ride an exercise bicycle until they reached their target heart rate and maintained that heart rate for at least 30 seconds. After treatment, subjects' heart rate and blood pressure were measured again, in order to indicate the physiological change induced by the stress of moderate exercise. All subjects repeated the fine motor skills assessment using the same pegboard to observe any changes from the baseline measurements. The subjects also recorded their physical exertion by filling out a survey using the Borg rating of perceived exertion scale (CDC 2011). The test subject was their own positive control from before moderate exercise. There was also a negative control group that did not perform any exercise in between pegboard testing. Rather, they sat for approximately three minutes in between tests, which is about the time it took for the experimental participants to reach their target heart rate on the exercise bike. The results of this group were intended to indicate if any changes in performance on the pegboard test were due to a learned response from repeating the same task within a short period of time.

Materials/Methods

When subjects first arrive, they were given a consent form and asked to read it and sign it if they wished to participate. They then rested for five minutes to ensure their heart rate was not elevated from climbing stairs or walking. Then each subject's resting heart rate was measured using a pulse oximeter. Measurements were taken every 20 seconds for two minutes and averaged, because a pulse oximeter does not give a consistent read out of heart rate. We also measured subjects' resting blood pressure using a manual blood pressure cuff, and then calculated the mean arterial blood pressure from that measurement. This was calculated by the formula ((2 * diastolic pressure) + systolic pressure)/3. For experimental subjects, these measurements were taken and compared to post-exercise values to ensure that subjects reached a level of physical exertion that could increase blood flow to the skeletal muscles.

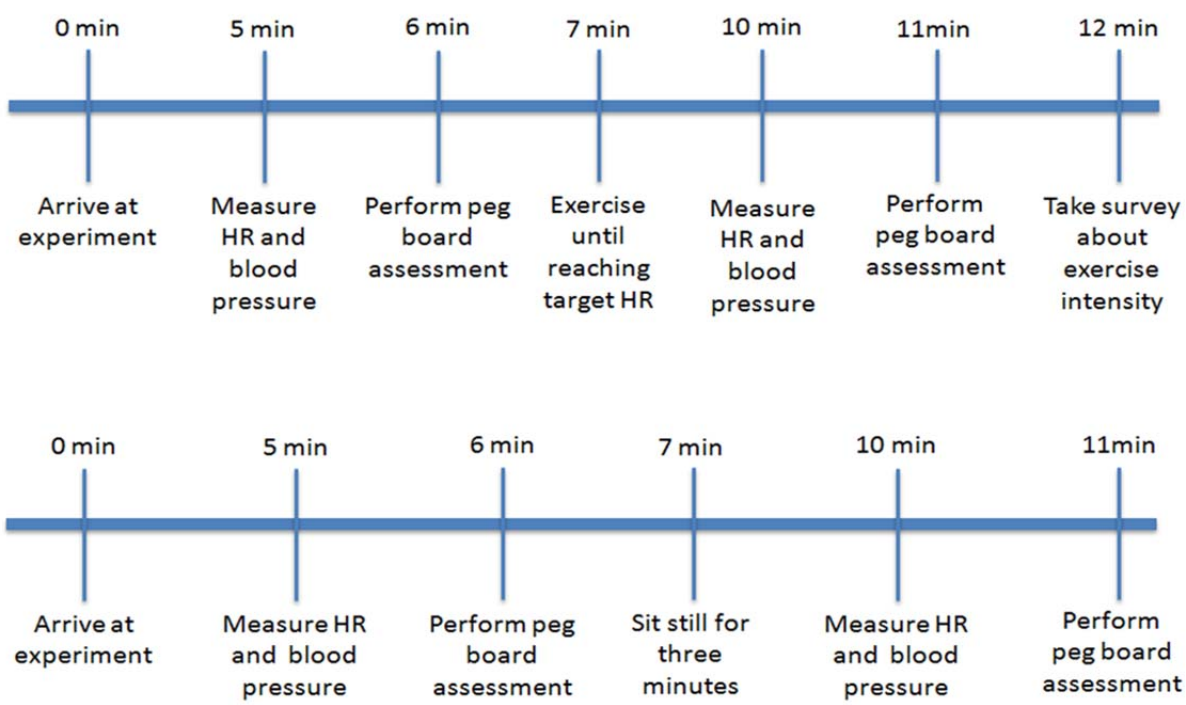
All subjects then performed a fine motor skill assessment by placing pins into the holes of a pegboard as quickly as possible, with the score being the number of pins placed in 30 seconds. All errors, such as dropping a pin, were counted as well. This statistic was used separately from the number of pegs placed successfully on the board. Only right-handed subjects were used in order to avoid any variability between right-handed and left-handed individuals. This was intended to eliminate any differences between the ambidexterity of right versus left-handed individuals.

Subjects undergoing the experimental protocol were then asked to ride an exercise bicycle until they reached their target heart rate and maintained that heart rate for at least thirty seconds. Target heart rate was determined by the formula (220 - age) * .6, or 60% of the subject's maximum heart rate, so that subjects reached a level of moderate physical exertion but not exhaustion. After treatment, subjects' heart rate was taken for one minute, and blood pressure was measured again. All subjects then repeated the fine motor skills assessment to observe any changes from the baseline measurements. A questionnaire was distributed after the experiment asking subjects to evaluate the intensity of the exercise, both overall, and on their arms and legs individually. The scale was based on Borg's perceived exertion scale, which goes from a "6", indicating no exertion, to a "20", indicating complete exhaustion. The survey also asked subjects to detail any factors that could have affected the experiment, which should allow us to see if any previous exercise could have interfered with the study.

Subjects undergoing the control protocol sat for three minutes after performing the first fine motor skills assessment. Then their heart rate and blood pressure was taken again, and they performed the fine motor skills assessment a second time. These subjects were intended to control for any learning that subjects may experience from doing the same task twice in a short period of time. Their heart rate and blood pressure was monitored in order to observe if there were any changes that could have potentially activated the sympathetic nervous response, especially in response to nervousness or stress that could have an effect on their performance on the pegboard assessment. These subjects did not fill out the questionnaire because they did not perform any exercise.

Below is a visual representation of the procedure that was conducted for the experimental and control group over the duration of the experiment.

Figure 1: Procedural Diagram



Statistical analysis was run at the conclusion of experimental testing to determine if there was a change in the mean number of pegs placed and errors recorded from before and after treatment, either experimental or control. These tests demonstrate if there is a statistical difference after exercise, or sitting as in the control group, which could indicate a learned response. Also, the experimental and control groups were compared to determine if there was any statistical difference between these groups, which could indicate a change in fine motor control that is not associated with a learned response.

Results

Of the subjects in the experimental group, there were nine males and twelve females with a mean age of 21.19 years of age. The control group consisted of four males and five females averaging 21.56 years of age. There was one female subject in the experimental group that has been omitted because of a pulse oximeter malfunction, and subsequent excessive exercise to near exhaustion based on her post-treatment survey. According to the post-experiment survey completed by the experimental group, the mean rating given by the students for the overall exertion was 10.42. The mean exertion rating of their arms was 7.26, and legs 10.47. These ratings correlate with light, extremely light, and light exertion respectively.

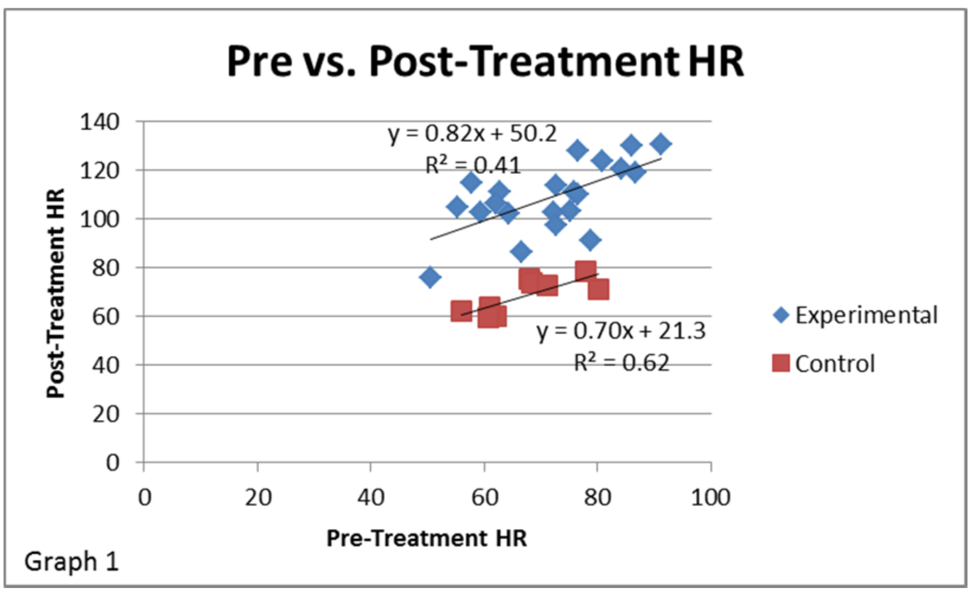
Many tests of statistical significance were run to explore the difference between the means of measurements among the experimental and control groups separately, but also between each group to test for differences between their measurements. All of the tests described below are two sample t-tests of means run at a 95% confidence interval ($\alpha=0.05$). There is also a table below summarizing the data described (Table 2).

Heart Rate

The experimental group had a mean pre-treatment heart rate of 71.86 beats per minute with a standard deviation of 11.17. The experimental group had a mean post-treatment heart rate that rose to 108.87 beats per minute with a standard deviation of 14.23. The average difference between pre- and post-treatment heart rate was 38.21 beats per minute and standard deviation of 11.09.

The control group had a pre-treatment mean heart rate of 67.28 beats per minute with a standard deviation of 8.13. Post-treatment, their mean heart rate was 68.52 beats per minute with a 7.22 standard deviation. The mean difference between pre- and post- treatment heart rate was 1.24 beats per minute with a 5.05 standard deviation.

Graph 1, below, shows that there is a positive relationship between pre- and post-treatment heart rate for both the experimental and control groups. While the pre-treatment heart rate is approximately the same for each, there is an increase in post-treatment heart rate for the experimental group.



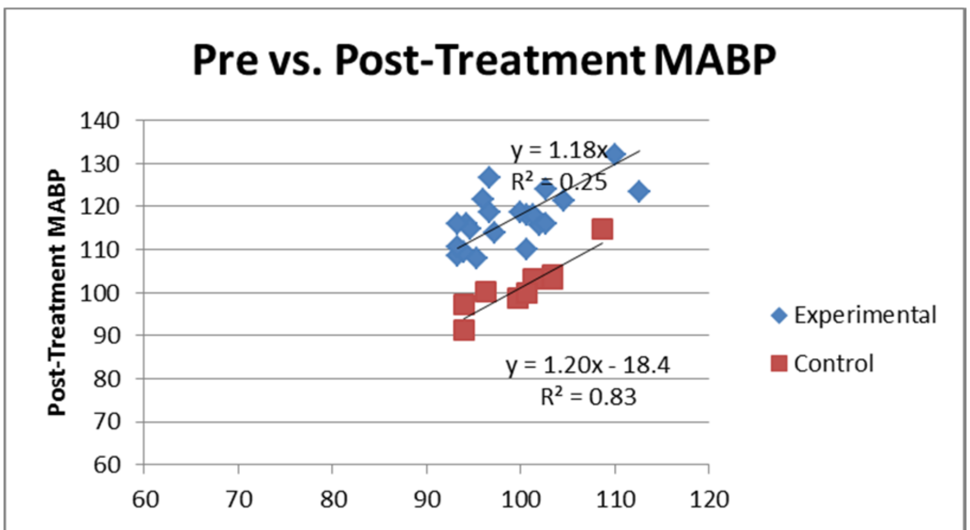
The null hypothesis that the mean heart rate pre- and post- treatment is the same was rejected in the experimental group with a p-value of 2.05×10^{-11}. The null hypothesis for the same measurement but for the control group was not rejected with a p-value of 0.74. This indicates that there was a statistically significant difference between the heart rate of subjects before and after treatment in the experimental group, but not in the control group.

Mean Arterial Pressure

The experimental group's mean pre-treatment mean arterial pressure was 99.16 with a standard deviation of 5.41. The average mean arterial pressure post-exercise rose to 117.21 mmHg with a 6.21 standard deviation, a mean difference of 17.67 mmHg with a standard deviation of 5.02.

The control group's average mean arterial pressure before treatment was 100.15 mmHg with a standard deviation of 4.81. Their average mean arterial pressure was 101.44 mmHg with a 6.31 standard deviation after treatment. The mean difference for mean arterial pressure was 1.67 mmHg with a 2.53 standard deviation.

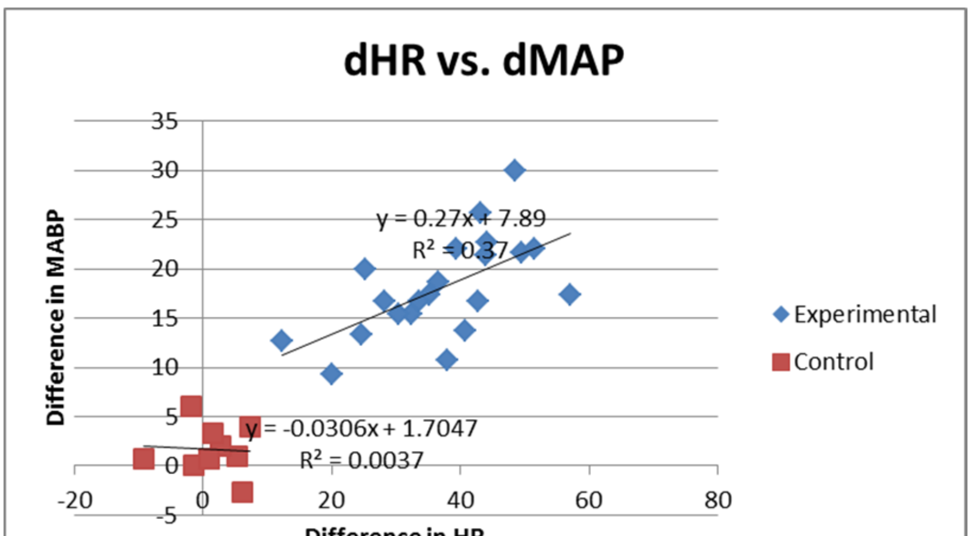
Graph 2, shows that there is a positive relationship between pre- and post-treatment mean arterial pressure for both the experimental and control groups. While the pre-treatment mean arterial pressure is approximately the same for each, there is an increase in post-treatment mean arterial pressure for the experimental group.



Graph 2

The results for mean arterial pressure were similar to heart rate, with a statistically significant difference between pre- and post- treatment measurements with a p-value of 2.14×10^{-12}. There was not a statistical difference for this measurement among the control group with a p-value of 0.63. Again, these results were expected. This indicates that there was success in increasing heart rate and mean arterial pressure through moderate exercise, while keeping it statistically equivalent in the control group not participating in moderate exercise.

Graph 3 is the relationship between the difference in heart rate and difference in mean arterial pressure before and after treatment. There was a moderate positive correlation in the experimental group, which indicates that as heart rate increases mean arterial pressure also increases. There was no perceived correlation in the control group, however.



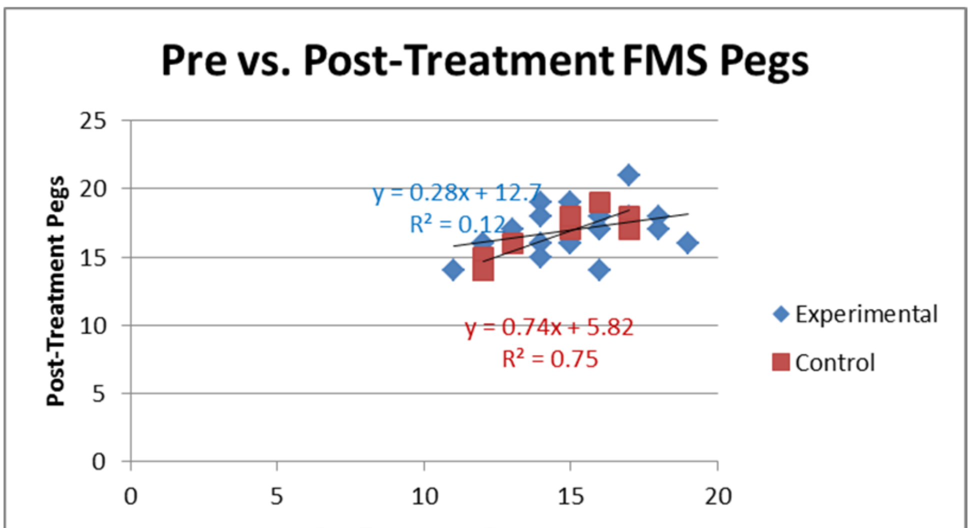
Graph 3

Pegs and Errors

The average number of pegs placed on the pegboard and errors recorded before exercise in the experimental group were 15.10 and 1.19 with standard deviations of 2.10 and 0.93 respectively. The average number of pegs placed and errors recorded after exercise were 17 pegs and 0.76 errors with standard deviations of 1.73 and 0.77 respectively. These are mean differences of 1.9 pegs and -0.38 errors with standard deviations of 2.21 and 1.36 respectively.

The average number of pegs placed and errors recorded prior to treatment in the control group were 14.33 pegs and 0.89 errors with standard deviations of 2.12 and 0.78 respectively. The number of pegs placed and errors recorded post-treatment were 16.44 pegs and 0.33 errors with standard deviations of 1.81 and 0.5 respectively. The mean differences between pegs and errors recorded were 2.11 pegs and -0.56 errors with standard deviations of 1.05 and 0.73 respectively.

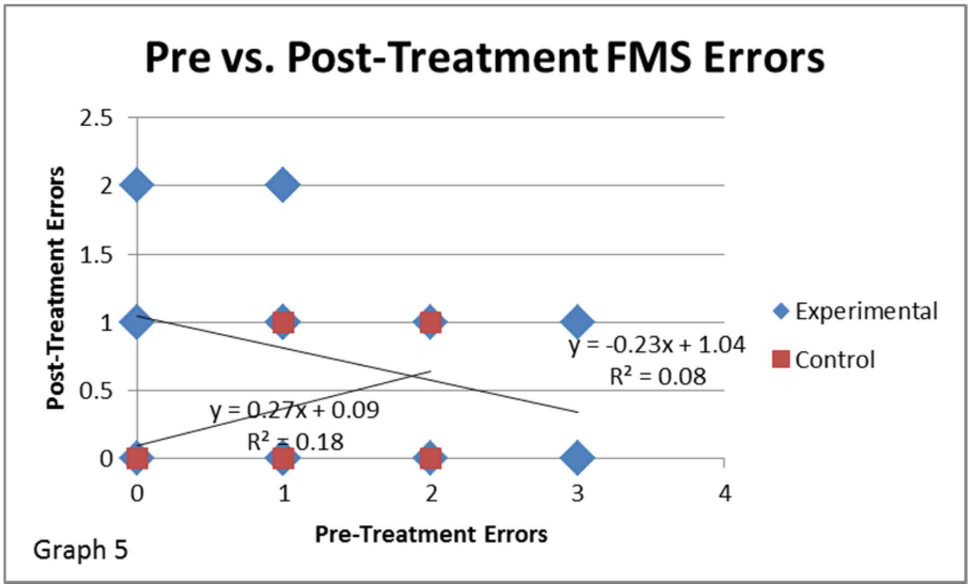
Graph 4 shows a slight positive relationship between pre- and post-treatment pegs placed for both the experimental and control groups respectively. However, there does not seem to be any difference between the experimental and control groups comparatively.



Graph 4

The difference between the mean number of pegs before and after treatment for the experimental group was found to be statistically significant with a p-value of .0027. This means that there was a statistical difference between the number for pegs before and after treatment for the experimental group, as hypothesized. Again, there was a statistically significant difference between the mean number of pegs placed before and after treatment for the control group with a p-value of 0.038.

Graph 5 shows the relationship between errors recorded pre- and post- treatment, however, there is minimal correlation between these variables with R^2-values of less than 0.2 for each group.



There was not a statistical difference between the number of errors before and after treatment for the experimental group. The p-value calculated was 0.11. Again, there was no statistical difference found between the numbers of errors before and after treatment for the control group with a calculated p-value of 0.09.

Lastly, there was found to be no statistical difference in the mean difference of pegs from before and after treatment between the experimental and control groups. With a p-value of 0.73, this test indicates that there is not a statistical difference between the experimental and control groups for the difference in the number of pegs placed before and after treatment.

The results were similar for the difference in errors for before and after treatment between the experimental and control groups. The p-value of 0.64 indicates that there is no statistical difference between these means. Both of these tests specify that no conclusions may be drawn between whether or not the treatment of moderate exercise changes fine motor control as tested by a peg board.

Below are tables to further organize the data described above.

	Age	Sex	Pre-HR	Pre-MAP	Pre-Pegs	Pre-Errors	Post-HR	Post-MAP	Post-Pegs	Post-Errors
Experimental										
Mean	21.19	9 males	71.86	99.16	15.1	1.19	108.87	117.21	17	0.76
Stand Dev	0.68	12 females	11.17	5.41	2.1	0.93	14.23	6.21	1.73	0.77
Control										
Mean	21.56	4 males	67.28	100.15	14.33	0.89	68.52	101.44	16.44	0.33
Stand Dev	0.73	5 females	8.13	4.81	2.12	0.78	7.22	6.31	1.81	0.5
	dHR	**dMAP**	**dPegs**	**dErrors**						
Experimental	38.21	17.67	1.9	-0.38						
	11.09	5.02	2.21	1.36						
Control	1.24	1.67	2.11	-0.56						
	5.05	2.53	1.05	0.73						Table 1

Statistical Analysis of Data									Table 2
**All below are 2-sample t tests of means at 95% confidence (α=0.05)									
Ho: $\mu_e-\mu_c=0$		Ho: $\mu_b-\mu_a=0$				B=before			
Ha: $\mu_e-\mu_c\neq0$		Ha: $\mu_b-\mu_a\neq0$				A=after			
Difference between the mean increase of pegs of Experimental vs. Control									
	Ẋ	STDEV	n						
Exper:	1.9	2.21	21	t=-.35	p=0.728	df=27.501		Do not reject null	
Control:	2.11	1.05	9						
Difference between the mean number or errors of Experimental vs. Control									
	Ẋ	STDEV	n						
Exper:	-0.38	1.36	21	t=.47	p=.642	df=26.32		Do not reject null	
Control:	-0.56	0.73	9						
Number of pegs before and after treatment									
	Ẋ	STDEV	n						
Exp: B:	15.1	2.1	21	t=-3.212	p=0.0027	df=38.63		Reject the null	
Exp: A:	17	1.73	21						
Cont: B:	14.33	2.12	9	t=-2.271	p=.0377	df=15.61		Reject the null	
Cont: A:	16.44	1.81	9						
Number of errors before and after treatment									
	Ẋ	STDEV	n						
Exp: B:	1.19	0.93	21	t=1.628	p=0.112	df=38.65		Do not reject null	
Exp: A:	0.76	0.77	21						
Cont: B:	0.89	0.78	9	t=1.797	p=0.946	df=13.6		Do not reject null	
Cont: A:	0.33	0.5	9						
HR before and after treatment									
	Ẋ	STDEV	n						
Exp: B:	71.86	11.17	21	t=-9.376	p=2.05E-11	df=37.867		Reject the null	
Exp: A:	108.87	14.23	21						
Cont: B:	67.28	8.13	9	t=-0.343	p=0.736	df=15.78		Do not reject null	
Cont: A:	68.52	7.22	9						
MAP before and after treatment									
	Ẋ	STDEV	n						
Exp: B:	99.16	5.41	21	t=-10.038	p=2.138E-12	df=39.26		Reject the null	
Exp: A:	117.21	6.21	21						
Cont: B:	100.15	4.81	9	t=-0.490	p=0.632	df=14.94		Do not reject null	
Cont: A:	101.44	6.31	9						

Discussion

Based on the data we collected, we were unable to draw any definite conclusions about the effects of moderate exercise on fine motor skills. There was a statistically significant difference in the number of pegs placed on the pegboard after exercise as compared to before exercise. However, the control subjects also exhibited a statistically significant difference in the fine motor skills assessment. The difference between the improvement of the experimental and control subjects was not statistically significant. In addition, neither the experimental nor the control group demonstrated a significant difference in the amount of errors made during the fine motor skills assessment from the first to the second time they performed it. Therefore, it is not possible to conclude that the experimental subjects experienced an improvement in fine motor skills as a result of moderate exercise. We also are unable to conclude that the increase in the number of pegs was due to a learned response that can result from doing the same task twice in a row because our sample size of nine subjects was not large enough to draw conclusions.

Our research team is confident that we sufficiently increased experimental subjects' heart rate and mean arterial blood pressure. Experimental subjects exhibited a statistically significant increase in heart rate after moderate exercise as compared to their resting heart rate, taken before exercise. These subjects also experienced a significant increase in blood pressure, as measured by the calculated mean arterial blood pressure, after exercise as compared to before exercise. As expected, the control subjects' heart rate and blood pressure did not undergo any statistically significant changes from the first time we took measurements to the second time measurements were taken, three minutes later. Therefore, we feel our methodology was sufficient to produce the desired increase in heart rate and blood pressure, and to potentially activate the sympathetic nervous response.

It is necessary, then, to attempt to explain why there was no observed difference between the improvement of fine motor skills of the experimental and control subjects. There were many potential sources of error in our research team's experimental design. The equipment being used, especially the pulse oximeter used to measure heart rate, was not always accurate. The pulse oximeter sometimes did not read correctly, resulting in people exercising for longer than intended, which could have caused some subjects to exercise to the point of exhaustion. In addition, the pulse oximeter occasionally resulted in difficulty taking measurements after exercise, allowing some people to recuperate for longer periods of time. Because we do not know for how long or the extent of sympathetic nervous response that could be activated by moderate exercise, it is possible that some of these subjects performed the second round of the fine motor skills assessment after the ideal window to observe the effects of this response.

Another potential source of error was that it was not possible to control for the physical fitness of our experimental subjects. As stated prior, Mueller (2007) stated that previous fitness levels and adiposity influence the significance of sympathetic response. The experimental protocol was to exercise until reaching 60% of the age-predicted maximum heart rate, and attempt to maintain this heart rate for 30 seconds. For some subjects who exercise regularly, it is possible that this level of physical activity was not intense enough or sustained enough to stimulate the sympathetic nervous response. For other subjects with a lower level of physical fitness, this amount of exercise pushed them to the point of near exhaustion, which could have affected their ability to perform the fine motor skills assessment. In addition, this methodology resulted in some people exercising for longer periods of time than others, depending on how long it took subjects to reach their target heart rate. This also could have an effect on the activation of the sympathetic nervous response. We attempted to observe differences in the perceived intensity of the exercise through the survey using Borg's scale of perceived exertion. While the results of this survey indicated that most subjects felt the intensity of exercise was low to moderate, it did not do anything to control for the effect of physical fitness on the physiological response to exercising. Time, measurement techniques, and number of subjects limited our ability to control for previous fitness levels and adiposity. Also, the minimal number of subjects made it difficult to observe conclusive results based on physical fitness level.

However, it is also possible that our initial rationale about how sympathetic nervous system activation affects peripheral blood vessels may have been flawed. In a study done by J. Timothy Noteboom et al., the researchers imposed stressors on subjects in order to stimulate the sympathetic nervous system, and they saw an overall decrease in steadiness when a pinch grip test was administered (2001). In response to environmental stress, the body will prioritize blood flow to the most important organs at that moment (Korthuis 2011). Because the appendages are not essential to survival, the effect of the "fight or flight" response may be to cause vasoconstriction in the hands. In the case of our study, because the arms and hands were not being actively exercised, the sympathetic nervous response may have constricted blood vessels necessary for fine motor movement. Therefore, while overall blood flow to the skeletal muscle increases as a result of sympathetic nervous system activation, it is possible that the proportion of this blood being supplied to the appendages necessary for fine motor skills decreases. When coupled with the potential learned response that comes with repeating the same task in a short period of time, this could explain why we did not observe any significant difference in the number of pegs placed between the control and experimental subjects.

In light of our inconclusive data and potentially flawed rationale, we have several ideas for improvements to our methodology that could increase our ability to draw conclusions from our data. First and foremost, we expect more conclusive data if a much larger sample size was possible, especially for our control group. With the number of subjects we currently have, one or two outliers can affect our results significantly. With a larger sample, the trends may show a stronger correlation, and therefore make it possible to draw significant conclusions.

In addition, we would like to obtain more consistent equipment if we were to repeat this experiment. An automatic blood pressure machine would eliminate any human error in taking blood pressure. We would also like to find a more accurate way of measuring heart rate. One potential solution would be to find a pulse oximeter that would send data to a computer, so that we would have a constant readout of heart rate. This would allow us to avoid the problem of having subjects inadvertently exercise for too long, or not being able to take measurements immediately after exercise.

Our research team would also like to control for each subjects' physical fitness level. We could potentially mitigate this problem by determining each subject's target heart rate based on their resting heart rate, which would help account for varying levels of fitness. We could also do a series of pilot studies where we could better gauge what "moderate exercise" is among varying individuals. This could be accomplished by having the subjects of the pilot study perform different intensities of exercise for varying lengths of time, and then complete a survey similar to the one in our study gauging the overall intensity of the workout. From this data, we could better determine how long subjects should exercise for, and at what intensity level.

If possible, we would perform this study over a period of at least 2 months to observe if consistent moderate exercise could affect the fine motor response in a more sustained way. Research has shown that long-term exercise programs can improve reaction time and motor performance along with the speed of cognitive processing (Rikli et al. 1991). With this methodology, we would have subjects come in one day, where we would measure the initial heart rate and blood pressure, and have subjects do the peg board assessment on that day. We would then have subjects perform a regimen of moderate exercise, as assigned by our research team, over weeks or months. After the determined period of time, subjects would return, exercise, and then perform the peg board assessment again. This would both potentially mitigate the learned response of doing the fine motor skills assessment twice in a short period of time, and would allow us to see the effects of continued moderate exercise on fine motor skills.

Literature Cited

Korthuis, Ronald J. "Exercise Hyperemia and Regulation of Tissue Oxygenation During Muscular Activity." *Skeletal Muscle Circulation*. San Rafael, CA: Morgan & Claypool Life Sciences, 2011. *National Center for Biotechnology Information*. National Institutes of Health. Web. 30 April 2014.

Mannheim, Jennifer K. "Fine motor control." U.S. National Library of Medicine. 27 Jan 2013. <http://www.nlm.nih.gov/medlineplus/ency/article/002364.htm>

Mueller, Patrick. "Exercise training and sympathetic nervous system activity: evidence for physical activity dependent neural plasticity." *Clinical and experimental pharmacology and physiology*. 34. (2007): 377-84. Web. 5 Feb. 2014. <http://www.ncbi.nlm.nih.gov/pubmed/17324153>.

Noteboom, J. Timothy, Monika Fleshner, and Roger M. Enoka. "Activation of the arousal response can impair performance on a simple motor task." *Journal of Applied Physiology*. 91 (2001): 821-831. Web. 23 April 2014.

Ozyemisci-Taskiran, O., Z. Gunendi, N. Bolukbasi, and M. Beyazova. 2008. The effect of single session submaximal aerobic exercise on premotor fraction of reaction time: An electromyographic study. Clinical Biomechanics. 23:231-235.

Parrott-Sheffer, Chelsey. "Human nervous system."*Encyclopedia Britannica*. 2013. <http://www.britannica.com/EBchecked/topic/409709/human-nervous-system/75584/Sympathetic-nervous-system

Rikli, Roberta E., and Diane J. Edwards. "Effects of a Three-Year Exercise Program on Motor Function and Cognitive Processing Speed in Older Women." *Research Quarterly for Exercise and Sport* 62.1 (1991): 61-67. *Taylor & Francis Online*. Informa UK Limited, 7 Feb. 2013. Web. 30 Apr. 2014.

Smith, P. J., J. A. Blumenthal, B. M. Hoffman, H. Cooper, T. A. Strauman, K. Welsh-Bohmer, J.N. Browndyke, and A. Sherwood. "Aerobic Exercise and Neurocognitive Performance: A Meta-Analytic Review of Randomized Controlled Trials." *Psychosomatic Medicine* 72.3 (2010): 239-52. Web. 23 April 2014

Spano, James F., and Edmund J. Burke. "Effect Of Three Levels Of Work Intensity On Performance Of A Fine Motor Skill." Perceptual and Motor Skills 42.1 (1976): 63-66. Ammons Scientific. Ammons Scientific. Web. 30 Apr. 2014

United States. Centers for disease control and prevention. *Physical activity*. Atlanta: , 2011. Web. <http://www.cdc.gov/physicalactivity/everyone/measuring/exertion.html>.