Effects of Exercise-Induced Changes in Blood Pressure, Heart Rate, and Oxygen Saturation on Visual Reaction Time

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Abstract

Physical exertion can influence numerous physiological indicators such as heart rate, blood pressure, and oxygen saturation of the blood. Previous studies linking these physiological effects to cognitive performance led us to ask whether physical exertion could cause a decreased state of alertness manifested as a slower reaction time. The purpose of this study is to examine how exercise affects reaction time. This potential correlation between exercise and reaction time would provide important insights into cognitive performance for application in the medical field. The participants performed an electronic reaction test before and after riding a stationary bike for one minute. Their heart rate, blood pressure, and oxygen saturation were also recorded both before and after exertion. It was hypothesized that the participants' average reaction time would be significantly slower after the exercise was performed, leading to a positive correlation between the physiological factors and reaction time. Results from a linear regression analysis did not show a significant relationship between elevated heart rate and reaction time (p-value: 0.5549). Systolic and diastolic blood pressure did not reveal a significant correlation either (p-value: 0.7271, p-value: 0.9394, respectively). Blood oxygen saturation showed a significant p-value of 0.006143, but this is believed to be skewed due to the presence of an outlier. A Welch two sample t-test showed that the sole treatment of exercise had no significant effect on reaction time with a p-value of 0.8943. Further research may examine the significance of a correlation between physical exertion and reaction time.

Introduction

Exercise is associated with a variety of immediate physiological changes in the human body. While exercising, the body's muscles consume ATP and oxygen at a much higher rate than while at rest. In order to compensate for this increase in consumption, the body's sympathetic nervous system increases cardiac output. This increase in cardiac output during exercise can be attributed to a slightly higher stroke volume and a substantial increase in heart rate. The body also delegates blood flow while exercising**,** leading to a slight increase in blood flow to the brain (Widmaier *et al.*, 2008). Systolic blood pressure increases linearly with increasing work, resulting in an overall increase in mean arterial blood pressure (U.S. Department of Health and Human Services; Pescatello *et al.*, 1991). This simultaneously allows for an increased rate of oxygen extraction from arterial blood as it passes through exercising muscle (U.S. Department of Health and Human Services).

While the immediate effects of exercise on physiological changes in the human body are relatively clear, the ramifications that these changes have on cognitive functions such as reaction time are less well-known. Previous studies have investigated the correlation between exercise and reaction time in humans with varying results. Certain sources have noted a significant slower reaction time in subjects exercising at high workloads (Ando, 2015; Ando *et al.*, 2008). Contradictorily, others have observed a faster reaction time in humans subjected to exercise at moderate-to-high intensities (Roach *et al.*, 2014). We aim to elucidate the effects of exercise on reaction time to visual stimuli through the use of various physiological measurements. We measured oxygen saturation using a pulse oximeter and heart rate and blood pressure with an automated blood pressure cuff both before and after exercise on a stationary bike. The subjects' visual reaction times before and after exercise were measured using a computerized reaction test, which measured the average time a user takes to react to visual stimuli over five trials. The physiological measurements taken before the exercise served as controls for each subject and were compared to the post-exercise measurements to establish a relationship between exercise and reaction time. A quarter of the participants served as negative controls and did not engage in any physical activity between the measurements.

The question of exercise and reaction time is important to study for several reasons, including application in the medical field. Examining the relationship between these two variables is important for this reason. For example, the Immediate Post-Concussion Assessment and Cognitive Testing, or ImPACT Test, which is "the most-widely used concussion evaluation system," compares a person's baseline performance on the test to performance when a concussion is suspected (Lovell, n.d.). One parameter the test uses to assess the person's state is reaction time. However, if an injury occurred during physical exercise, the athlete would have an elevated heart rate and blood pressure and a decreased O_2 saturation. Knowing whether these exercise-induced physiological changes affect reaction time is important since it could alter the ImPACT test results. In order to properly use the test to diagnose a concussion, this question must be resolved. There are also practical applications for this question. For instance, if a person drives to a gym, exercises, and immediately starts to drive home, an altered reaction time due to the previous exercise could have consequences or benefits.

While the relationship between exercise and reaction time remains uncertain, the individual impacts of heart rate, blood pressure, and oxygen saturation on reaction time have been studied with varying results. However, some studies suggest otherwise. Increased heart rate has previously shown a significant positive correlation with auditory reaction time (Lacey & Lacey, 1974). For this reason, we anticipated that heart rate would correlate with a slower visual reaction time as well. Van Boxtel et al (1997) showed that blood pressure has no correlation with cognitive performance, while others have suggested a link (Brisswalter *et al.*, 1997).

Oxygen desaturation has been linked in some cases to poorer performance on cognitive tests. Ando (2015) concluded that cerebral oxygen saturation may play a significant role in visual perception during exercise. Since exercise workloads lead to oxygen desaturation in the blood, we expect that exercise-induced hypoxia in the brain should lead to an impaired performance on a visual reaction test (Rowell *et al.*, 1964). Because elevated heart rate, elevated blood pressure, and oxygen desaturation have all been correlated with impaired cognitive performance in various studies, we hypothesize that exercise will cause a slower visual reaction time.

Methods

Materials

To complete the study, participants rode a stationary bike, the Cycle Trainer 390R (Gold's Gym Inc; Irving, TX). A Nonin Pulse Oximeter/Carbon Dioxide Detector (Model 9843; Nonin Medical Inc; Plymouth, MN) and Omron 10 series+ blood pressure monitor (Model BP791IT; Omron Healthcare, Inc; Lake Forest, IL) were utilized to take the physiological measurements from each subject. Visual reaction times were recorded with an online reaction test (https://faculty.washington.edu/chudler/java/redgreen.html).

Participants

A total of 29 participants, 16 females and 13 males, age 21-22, were tested. 21 of these were included in the experimental group, while the other 8 comprised the negative control group.

Procedure

Prior to each participant's arrival, the testing room was prepared. Tables were set up on both sides of the stationary bike where each subject sat for the duration of the experiment. The table on the right held a laptop and mouse for the subject to complete an online reaction test. This test was designed to measure the user's average time to react to randomly spaced visual stimuli over five attempts (Allen, 2002). The table on the left held the blood pressure monitor and pulse oximeter. Blood pressure was measured using the Omron 10+ series blood pressure monitor, and O_2 saturation and heart rate were measured using a Nonin Pulse Oximeter/CO_2 Detector. Prior to beginning experimental data collection, five individuals for a pilot study group were tested to ensure that the equipment and study design were sufficient to measure changes in the proposed physiological variables (Table 1).

To begin the study, each subject entered the room and was instructed to sit on the bike and fill out a consent form and questionnaire detailing the subject's recent physical activity, visual impairments, heart or respiratory problems, and food consumption prior to arriving

(Appendix A). The subject was then given a brief overview of the experimental procedure and detailed instructions on how to perform the reaction time test. While remaining seated on the bike, the blood pressure cuff and Pulsox finger monitor were placed on the subject. The blood pressure cuff was placed on the left arm while the Pulsox finger monitor was worn on the right ring finger. This allowed the participant to perform the reaction test and pedal while wearing the Pulsox finger monitor.

To begin data collection, the subject's blood pressure, heart rate, and oxygen saturation were measured simultaneously and recorded. These served as the initial measurements. The subject was then instructed to complete an initial reaction test, after which the average reaction time was recorded. The subject was then instructed to pedal for one minute at a set resistance of 5 while trying to maintain a speed of 20 mph. If the subject served as a negative control, the subject was instructed to sit on the bike for one minute with no activity. Immediately after the subject completed the exercise, post-exercise measurements of blood pressure, O_2 saturation, and heart rate were recorded in the same manner as the initial measurements. Finally, the subject performed a second reaction test and the average reaction time for the second set of trials was recorded, completing the experiment. A timeline of events throughout the course of the study is presented in Figure 1.

Results

T-test

A Welch two sample t-test was run comparing the mean changes in reaction time between the control group, comprised of subjects who did not undergo the period of physical exertion, and the treatment group, comprised of subjects who did undergo the period of physical exertion. It was found that the effects of induced exercise on reaction time yielded nonsignificant results with a P-value of 0.8943, suggesting that the exercise treatment in itself did not produce a measurable change in reaction time.

Heart Rate

Linear Regression analysis revealed no significant induced change in reaction time (p=0.5549) in relation to heart rate between the control and experimental groups (Table 2).

Systolic Blood Pressure

Linear Regression analysis revealed no significant induced change in reaction time (p=0.7271) in relation to systolic blood pressure between the control and experimental groups (Table 2).

Diastolic Blood Pressure

Linear Regression analysis revealed no significant induced change in reaction time (p=0.9394) in relation to diastolic blood pressure between the control and experimental groups (Table 2).

Blood Oxygen Saturation

Linear Regression analysis revealed a significant induced change in reaction time (p=0.006143) in relation to blood oxygen saturation between control and experimental groups (Table 2). This significance is driven by a single outlier.

Discussion

The difference in overall change in heart rate, systolic blood pressure, diastolic blood pressure and blood oxygen saturation between the negative control group and experimental group indicate that there was a measurable difference in physiological response. The experimental group had a larger overall positive increase in heart rate, systolic blood pressure, and diastolic blood pressure and an overall decrease in blood oxygen saturation. Our control group served as the basis of comparison for the experimental group. No significant change in reaction time was observed between the experimental and control groups for heart rate, systolic blood pressure or diastolic blood pressure. Therefore, we can conclude that although these factors changed due to exercise, they do not have a significant effect on reaction time. This does not support our hypothesis that exercise induced changes in heart rate and blood pressure will lead to a slower reaction time. Blood oxygen saturation did show a significant decrease in reaction time when compared to the control group, but this can be explained by an outlier. This contradicts our hypothesis, as the reaction time was faster when only looking at blood oxygen saturation. However, the presence of an outlier suggests that it is not safe to conclude that decreased blood oxygen saturation leads to a faster reaction time.

Although heart rate did not produce significant results, figure 3 shows that a slight negative trend does exist between heart rate increase and reaction time. The control group for heart rate (Figure 2) shows the opposite trend. Due to these data showing no significant results, we can not use this to draw conclusions about our results.

Systolic blood pressure and diastolic blood pressure also did not produce significant results. Figures 5 and 7 show that a greater increases in systolic pressure and diastolic pressure show a slight trend with a slower reaction time. The control data for systolic and diastolic blood pressure show the opposite trend compared to experimental data (Figures 4, 6). This trend might suggest that the immediate hypertensive state of the participant has a detrimental effect on visual processing as it relates to reaction time. These data are insignificant and cannot be used to draw any conclusion.

Blood oxygen saturation was the only physiological variable that was measured that had a significant effect on the reaction time between control and experimental groups. The control data for blood oxygen saturation shows a slight positive relationship between decreased saturation and decreased reaction time (Figure 8). This significant result is driven by an outlier who had a large decrease in reaction time as well as in blood oxygen saturation. A more negative change in blood oxygen saturation correlates with a faster reaction time as shown by figure 9**,** which contradicts our hypothesis**.**

The accuracy of our results could have been affected by many various factors. Occasionally we experienced problems with the equipment used to measure physiological responses. The blood pressure monitors used during the experiment may not have been positioned correctly on the participant's arm, or read errors in circumstances of very high blood pressure leading to inaccurate measurement of blood pressure. Additionally, some participants did not ride the stationary bike in a manner which significantly elevated their heart rate, blood pressure, and oxygen saturation as compared to other participants. The blood oxygen saturation measurement may also have been affected by the positioning of the monitor on the finger of the participants. Participants may have also experience a physiological response prior to riding the exercise bike due to the questionnaire (Appendix A) asking a few personal questions, or taking part in a separate study that also influenced our measured physiological responses. According to our questionnaire, many participants had different confounding factors including a family history of heart and high blood pressure, asthma, glasses, exercised previously, or consumed stimulants which could have varying effects on results. There is also a possibility for other factors not included in our questionnaire that may have altered their normal levels for physiological factors.

To combat these factors, participants could have been asked to sit in a peaceful state to lower their heart rate, and blood pressure while allowing their blood oxygen saturation to return to a normal value during a rested state after filling out the questionnaire. Additionally, more accurate blood pressure monitors could be used to alleviate human error in regards to cuff positioning. In regards to the manner in which participants rode the stationary bike, time measured while riding the bike should be limited to the time at or above the desired speed. To be completely consistent in regard to consumption, asking participants to refrain from eating or drinking before taking place in the study would alleviate any confounding dietary factors.Future studies consisting of a more rigorous induced exercise regimen could lead to more profound measureable changes in the physiological responses. Also, to expand on the experiment, more physiological parameters could be included besides those tested in this paper since exercise has such a diversified effect on the body. Future experiments could use these adjustments to help control for confounding variables to produce more accurate results. If more research is performed this could help to aid and bolster current medical knowledge. New developments could lead to better diagnosis of concussions via the ImPACT test which is very important especially now as researchers are currently in the midst of new developments concerning concussion treatments.

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Tables

Table 1. Positive control data for five subjects. Changes in the physiological variables of heart rate, blood pressure, and oxygen saturation, as well as visual reaction time, were recorded both before and after a one-minute period of physical activity.

Initial	Subject 1	Subject 2	Subject 3	Subject 4	Subject 5
Heart Rate	53	61	66	87	68
Blood Pressure	121/57	113/71	114/67	111/82	140/81
Blood O_2 Saturation	99	99	98	97	97
Reaction time	0.2814	0.2764	0.341	0.2888	0.2775
Final					
Heart Rate	85	79	105	108	90
Blood Pressure	126/56	125/57	119/85	134/75	158/83
Blood O_2 Saturation	98	97	98	97	94
Reaction Time	0.2804	0.288	0.3192	0.2638	0.2702

Table 2. P-values of measured variables compared to reaction time from Linear regression analysis.

Measured Variable	**P-Value**
Heart Rate	0.5549
Systolic Blood Pressure	0.7271
Diastolic Blood Pressure	0.9394
Oxygen Saturation	0.006143
Reaction time	0.8943

Figures and Legends

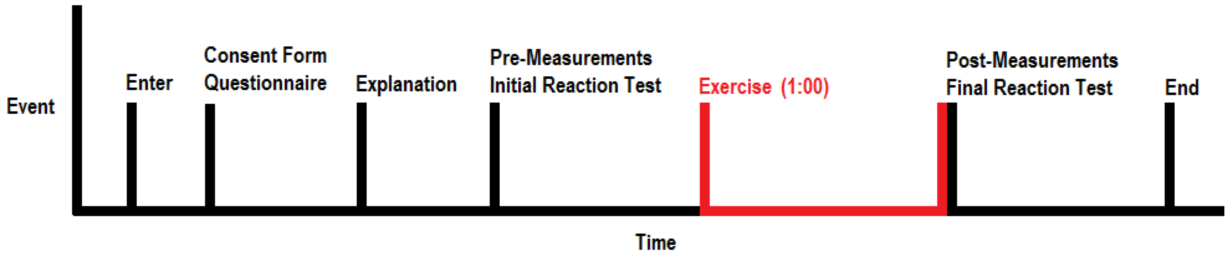

Figure 1. Timeline representation of the experimental procedure used to assess visual reaction time, blood pressure, O_2 saturation, and heart rate before and after a one-minute period of physical exertion.

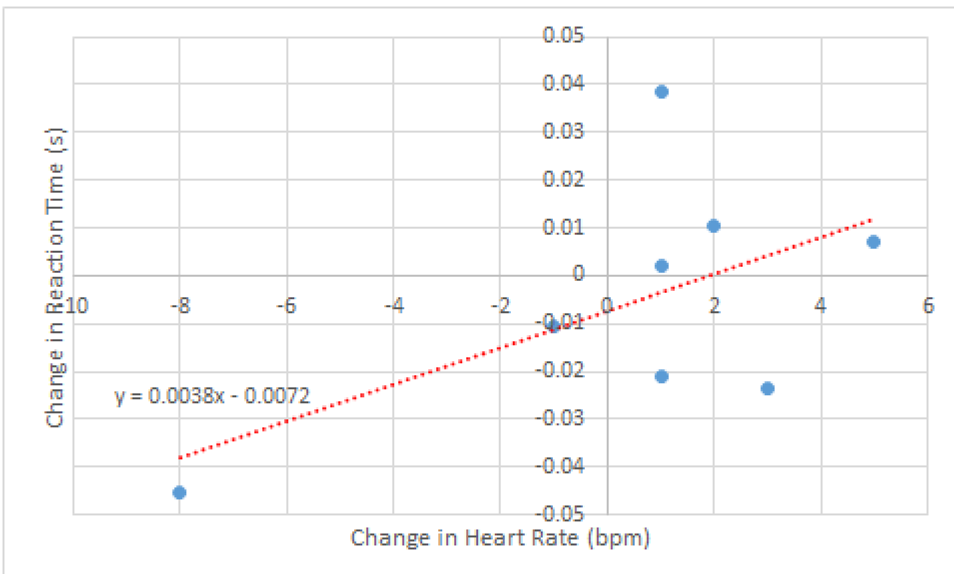

Figure 2. Comparison of the change in reaction time (seconds) with the change in heart rate (beats per minute) for the eight control subjects.

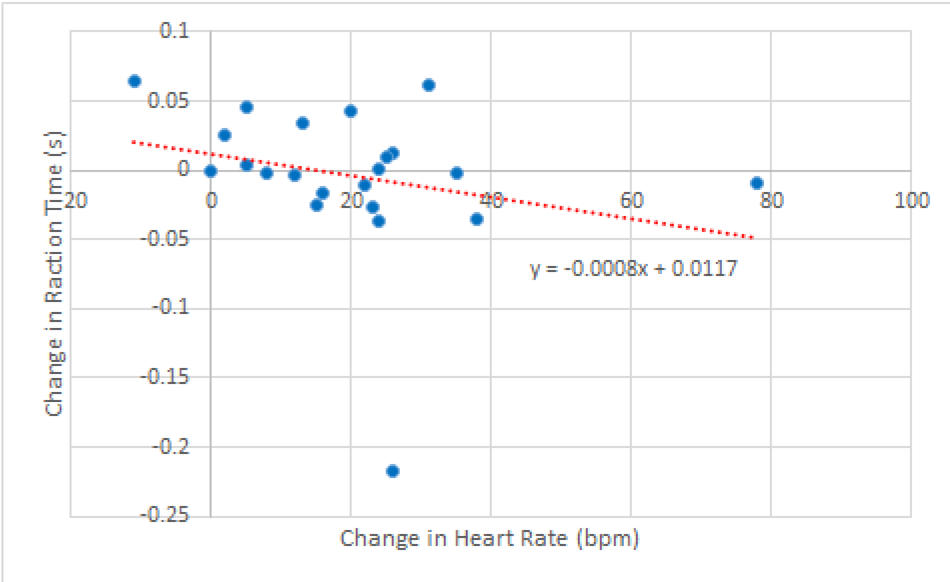

Figure 3. Comparison of the change in reaction time (seconds) with the change in heart rate (beats per minute) for the 21 experimental subjects.

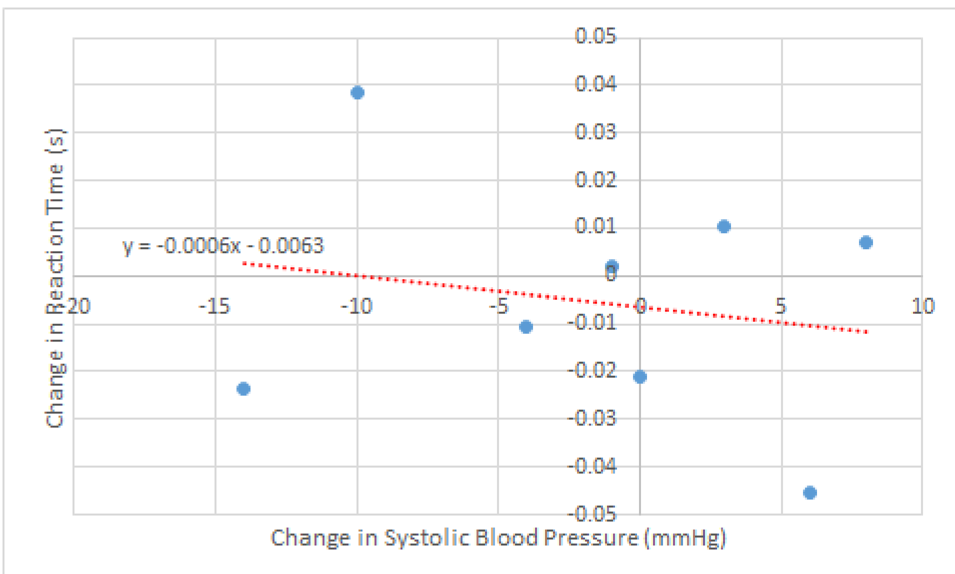

Figure 4. Comparison of the change in reaction time (seconds) with the change in systolic blood pressure (mmHg) for the 8 control subjects.

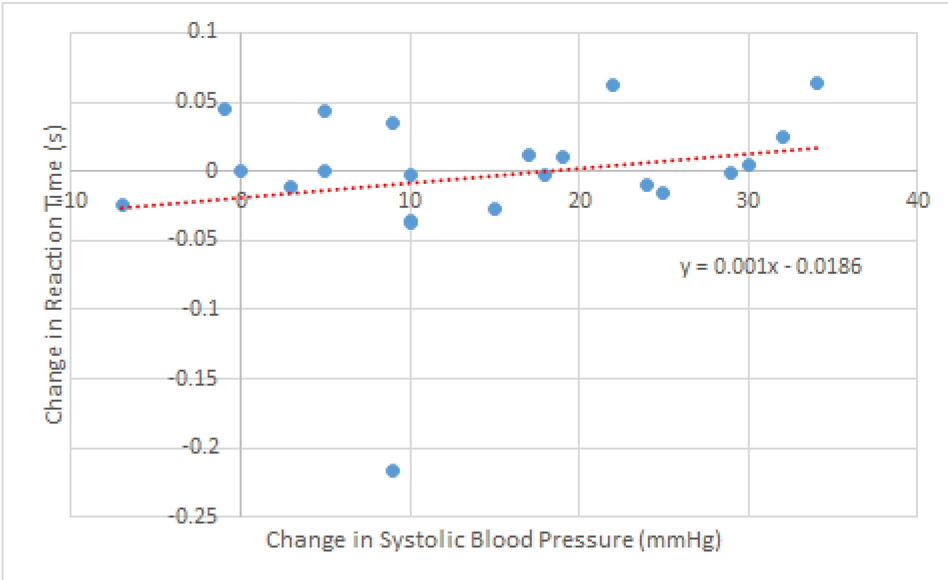

Figure 5. Comparison of the change in reaction time (seconds) with the change in systolic blood pressure (mmHg) for the 21 experimental subjects.

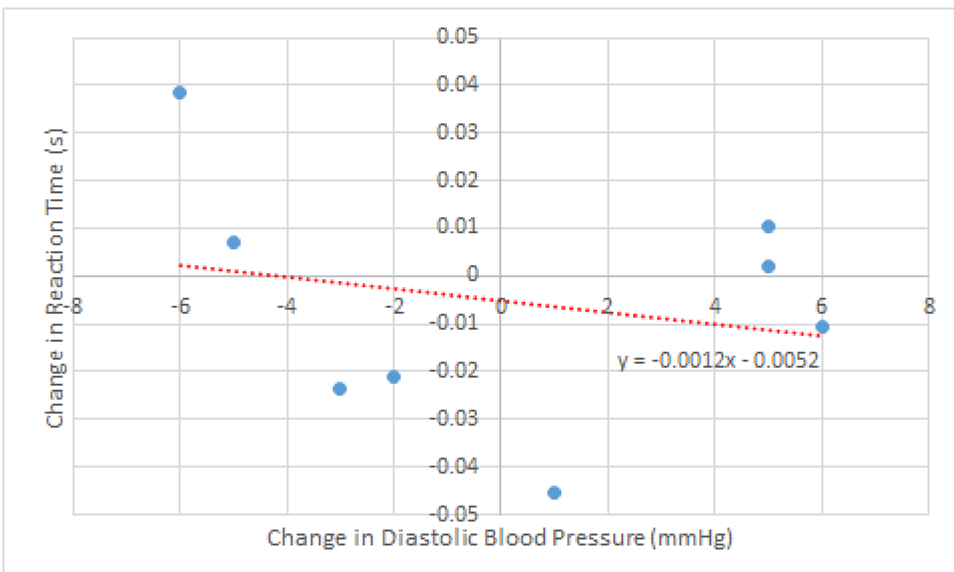

Figure 6. Comparison of the change in reaction time (seconds) with the change in diastolic blood pressure (mmHg) for the 8 control subjects.

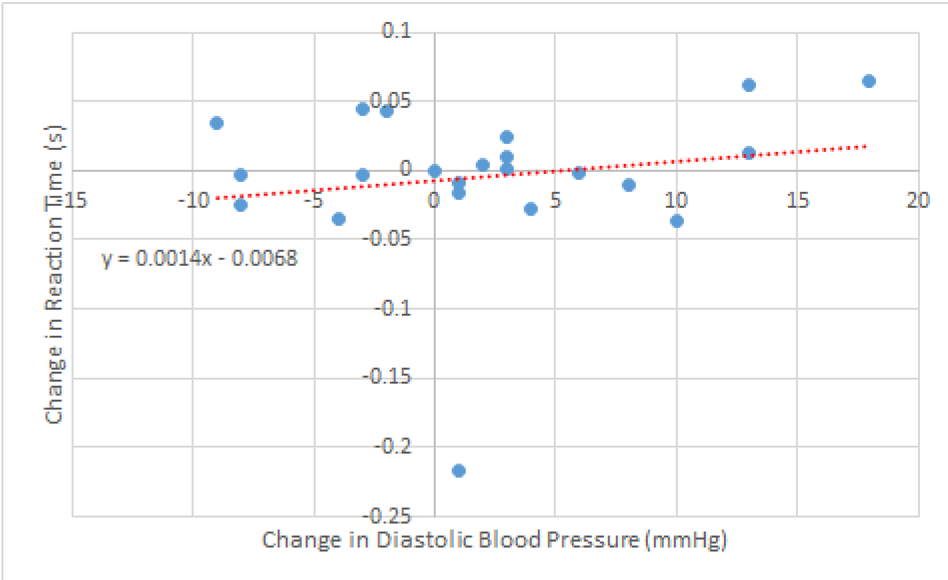

Figure 7. Comparison of the change in reaction time (seconds) with the change in diastolic blood pressure (mmHg) for the 21 experimental subjects.

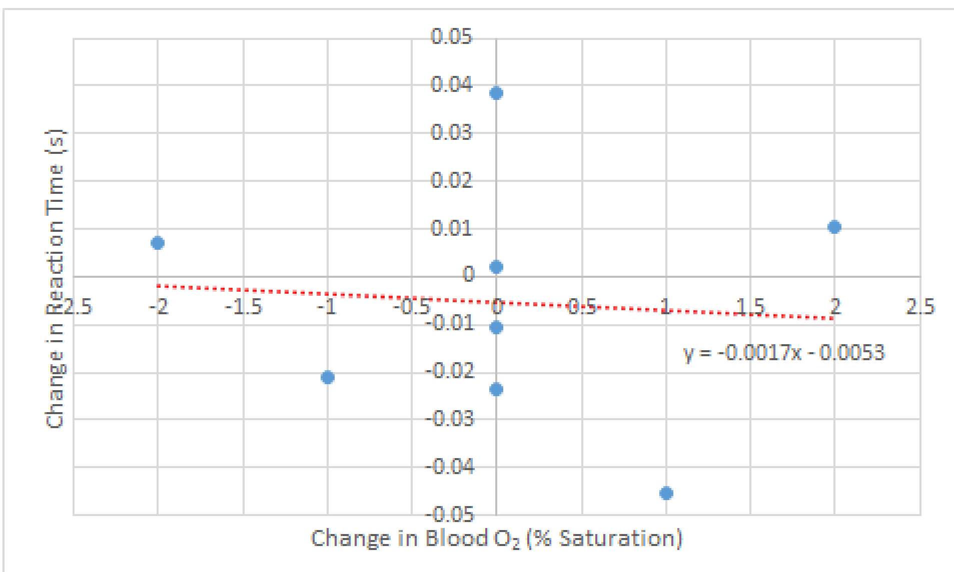

Figure 8. Comparison of the change in reaction time (seconds) with the change in blood oxygen (% saturation) for the 8 control subjects.

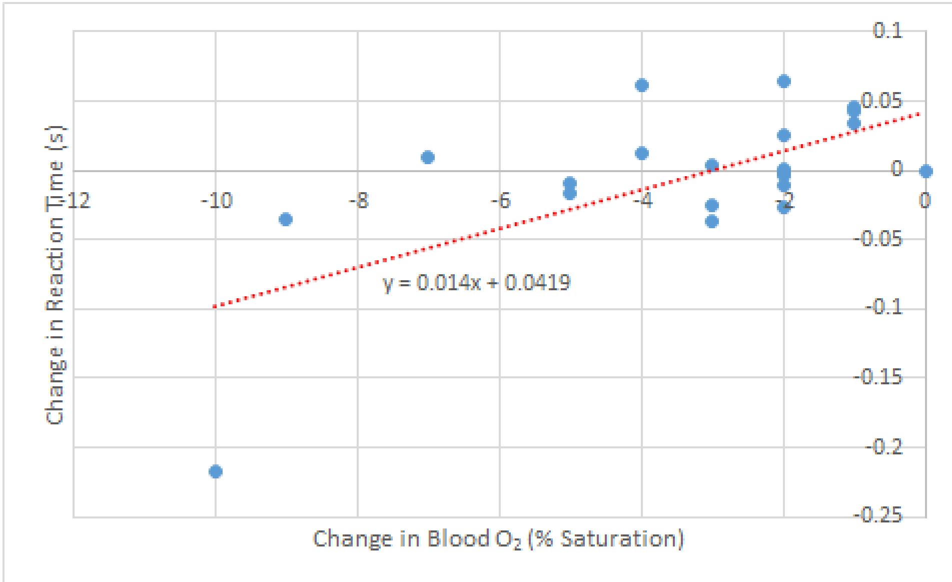

Figure 9. Comparison of the change in reaction time (seconds) with the change in blood oxygen (% saturation) for the 21 experimental subjects.

Appendix A

Group 16 Research Study Questionnaire

Participant Number:______________________________
Date:___________________
Age:______________________________
Male/Female

1. Do you have a history of high blood pressure in your family?

____

2. Do you have a history of heart problems in your family?

____

3. Do you have asthma or any other respiratory problems?

____

4. Do you wear glasses or contacts?

____

5. Are you color blind?

____

6. Have you worked out today?

____

7. Do you currently play any competitive sports?

____

8. How many days a week do you exercise?

____

9. How many hours a week do you exercise?

____

10. What did you consume today?

____

Appendix B

UNIVERSITY OF WISCONSIN-MADISON
Research Participant Information and Consent Form

Title of the Study: How exercise-induced changes in blood pressure, heart rate, and O2 saturation impact reaction time to visual stimuli.

Principal Investigators: Charles Giuliani, Cody Lukes, Joe Kern, Michelle Kleitsch, Jocelyn Zajac

DESCRIPTION OF THE RESEARCH

You are invited to participate in a research study about the effect of induced exercise on reaction time.

You have been asked to participate because you are enrolled in Physiology 435.

The purpose of the research is to try to identify a correlation between heart rate, blood pressure and/or blood oxygen saturation and visual reaction time.
____

This study will invite the participation of all students enrolled in Physiology 435.

This research will take place within Physiology 435 laboratory sections.

WHAT WILL MY PARTICIPATION INVOLVE?

If you decide to participate in this research you will be asked to participate in a reaction time assessment, ride a stationary bike at medium-high intensity for one minute, as well as give blood pressure, O2 saturation, and heart rate measurements before and after.________________________

Your participation will last approximately 5 minutes.
____

After the semester is completed, the study may be published in the Journal of Advanced Student Science.
____.

No credit compensation will be given for your complete and voluntary participation. If you do not wish to participate, simply return this blank consent form.

.**ARE THERE ANY RISKS TO ME?**
____
______________There are no immediate risks if you have no pre-existing conditions.

ARE THERE ANY BENEFITS TO ME?

You get the chance to be a part of novel research that could lead to improvements in cognitive ability and the diagnosis of head trauma.

____.

HOW WILL MY CONFIDENTIALITY BE PROTECTED?

While there may be printed reports as a result of this study, your name will not be used. Only group characteristics will be reported – that is results with no identifying information about individuals will be used in any reported or publicly presented work.

WHOM SHOULD I CONTACT IF I HAVE QUESTIONS?

If you are not satisfied with response of research team, have more questions, or want to talk with someone about your rights as a research participant, you should contact Dr. Andrew Lokuta, 608-263-7488, ajlokuta@wisc.edu.

Your participation is completely voluntary. If you decide not to participate or to withdraw from the study it will have no effect on your grade in this class.

Your signature indicates that you have read this consent form, had an opportunity to ask any questions about your participation in this research and voluntarily consent to participate.

Name of Participant (please print):________________________________

____

Signature ________________________ Date