Exercise Induced Sympathetic Nervous System Activation and its Influence on Memory and Comprehension

Christopher Dinh, Jordon Michalske, Sarah Nabong, Tarek Amro and Sophia Kallas

University of Wisconsin-Madison, Department of Physiology

Physiology 435

Lab 302, Group 9

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Abstract:

In this study, the relationship between sympathetic nervous system activity induced by stress and its effect on memory and comprehension were investigated. The three variables: heart rate, blood pressure, and electrodermal activity were measured in order to investigate the sympathetic nervous system response of 50 participants from the University of Wisconsin-Madison Anatomy & Physiology 435 class. These 50 participants were divided into two groups, one having to bike for a period of eight minutes and one being sedentary. Both groups were required to watch a five-minute Khan Academy video on Macroeconomics during their eight minutes of participation. Then, the groups were compared on their performance of a questionnaire that would test their overall memory and comprehension of the material presented in the video. Overall, the biking and sedentary groups did not show any significant difference in performance on the questionnaire with a p-value = 1. Therefore, this study did not find that sympathetic nervous system activity induced by physical stress had a meaningful influence on memory and comprehension.

Introduction:

Scientific research has been used as a tool to discern the environment needed for adequate acquisition of knowledge. Since the years of 1990-1999, called the decade of the brain, and in later years, the decade of the mind, numerous studies have sought to use science to inform the basis of how we learn (Sousa 2010). Throughout these years, many suggestions for educational instruction have resulted in gross misinterpretations of scientific data resulting in scientific myths. This is due to a lack of coherent and all-encompassing experimental research.

These suggestions, if not critiqued closely, find themselves implemented in the classroom setting (Bruyckere 2019).

One such suggestion to how we learn, with little experimental evidence, is whether exercise in the classroom can improve memory and comprehension (Johnson & Jones 2016). Our research team argues that by understanding the fundamental principles of how the body functions, we can better understand insights into more involved processes such as memory and comprehension. One such question of interest that our team would like to investigate is how the activation of the sympathetic nervous system (SNS) due to physical stress plays a role in memory and comprehension. This smaller stepping stone allows for a better understanding of the basic physiological responses that underlie periods of moderate physical stress. These physiological data points may influence SNS activity and can potentially factor into more complex cognitive functions like memory.

It is known that when the SNS is activated, it can cause rapid physiological, behavioral, and even cognitive changes. The SNS is a division of the autonomic nervous system. This is one of the main body systems used to maintain homeostasis. The processes of the SNS are stimulated to trigger the “fight-or-flight" response to perceived stress or harm. This typical human stress response can cause a series of physiological changes such as: an increased heart rate, increased blood pressure, dilated pupils, slowed digestion and more.

One such physiological change that occurs is the release of the hormone called epinephrine from the adrenal glands. Epinephrine can cause the breakdown and release of stored glucose and fatty acids in preparation for a stressful event. This stress hormone affects the “encoding, consolidation, and retrieval of memories” during periods of stress (Smeets *et al.* 2008). In a previous study conducted at Maastricht University in the Netherlands, researchers showed that participants who were exposed to an *emotional stres*s, released epinephrine immediately prior to the encoding of information. The release of epinephrine demonstrated memory-enhancing effects (Smeets, *et al.* 2008). This suggests that the initial experience of encoding information into a memory can be modulated by the release of stress hormones such as epinephrine.

Furthermore, the encoding of memory by stress hormones is attributed to the innate instincts of animal survival and fitness. In general, animals rely on memory and learning to adapt to their environments, especially in situations of great stress or danger (Pravosudov 2019). In order to avoid such stressful events in the future, animals must encode the memory accurately. In the past, studies have shown that stress hormones released by the SNS correlate with improved memory consolidation (Cahill et al. 2002). However, most studies have used an emotional trigger to stimulate the SNS. The effects of sympathetic activation and the subsequent release of stress hormones by *physical stress* (exercise) on memory and comprehension remains largely ambiguous.

Exercise has continuously been correlated with improved cardiovascular health, but its effects on the brain have not been highlighted in the same way. Staying active has been shown to improve memory and attention by the promotion of neurogenesis, the birth of new cells (Postal). Additionally, it is found that those who exercise regularly are 50 percent less likely to develop dementia than those who do not (Postal). Also, there have been associations between after exercising and improved attention and cognitive thinking - with stronger performance on problem solving and memory tasks (Postal).

The three physiological variables measured in order to determine exercise levels of participants were electrodermal activity (EDA), heart rate, and blood pressure. Blood pressure during exercise is a predictor of someone's cardiovascular health with higher values of blood pressure associated with endothelial cell dysfunction in adults (Lambiase et al. 2014). Furthermore, the sympathetic nervous system has been shown to have a significant role in controlling blood pressure in the short term, but there have been studies showing an overall link between hypertension and elevated SNS (Fisher et al. 2011). When there is prolonged activation of SNS activity, it has been associated with a plethora of issues throughout the systems of the body, due to high levels of cardiac stress (Fisher et al. 2011). Additionally, with higher activation of the SNS, heart rate will be generally increased due to the release of epinephrine. As with blood pressure, heart rate (normal range of 60-100 beats per minute) is usually elevated with the release of stress hormones which can contribute to a higher prevalence of cardiac morbidity and mortality (Gordan et al. 2015).

The variable electrodermal activity (EDA) is a way to measure sympathetic activity in skin. EDA is specifically defined as a tool to measure "skin conductance" through the "autonomic innervation of sweat glands." EDA therefore can give researchers data specifically on sympathetic activity (Posada- Quintero et al. 2018). Usually as exercise increases so does EDA, but in this study, we will look to analyze how this coeffects SNS activity with a specific memory and learning task. With these three variables being influenced by the SNS, we hope to investigate the overall role that the SNS plays on memory and comprehension with the induction of physical stressors.

Our study seeks to investigate whether moderate exercise, and therefore SNS activation, can influence the encoding of stress induced memories and the more involved cognitive processes such as comprehension and memory retention. We hypothesize that moderate exercise will activate and increase sympathetic activation and thus improved memory and overall comprehension.

Materials

Three variables were analyzed in this experiment in order to determine whether there was a relationship between comprehension and moderate physical activity. The three variables analyzed included heart rate, blood pressure, and EDA. Heart rate was measured by using a pulse oximeter detector (Model: 9843 SN: 118102909 Nonin Medical, Inc. Minneapolis, MN) to record the beats per minute. Systolic and diastolic blood pressure data were measured using a battery- operated blood pressure cuff (Model: BP791IT SN:20141004362LG Omron Health Care, Inc. Sunrise, FL). Electrodermal activity (EDA) was recorded via an electrodermal transducer (Model: SS3LA, SN:12092152, BIOPAC Systems, Inc. Goleta, CA). Data recording and analysis was carried out with the BIOPAC Student Lab System (BSL 4 Software, MP 36) along with consultation from the BIOPAC Systems, Inc. Student Manual (ISO 9001: 2008, BIOPAC Systems, Inc.) for equipment set up. A Khan Academy video focusing on Macroeconomics ("Components of GDP") was shown to participants with half of the randomly selected population sitting in a chair and the other half performing moderate exercise on a stationary bike (Model: Cycle Trainer 390R Serial Number: EE251H). The video was played in order to observe any measurable differences in the participant's EDA that occurred with the addition of moderate exercise in relation to the participants that were only sitting. One standard Dell computer was used to retrieve, monitor, and analyze data collected by the BIOPAC system. A MacBook pro computer was used to play the educational video. A google form, an online survey software, with five questions was then utilized and sent to the participants a week later to assess each participant's level of comprehension and memory. Both the assessment and EDA were collected in order to determine if there was a correlation between increased EDA and the level of successful memory and comprehension performance in answering the short assessment pertaining to the presented video.

Methods

Participants (Screening and Consent)

The participants of this study were chosen from the spring 2019 Anatomy and Physiology 435 course at the University of Wisconsin - Madison. Ages of the participants ranged from 19-25 years old and data measurements were collected at the UW- Madison Medical Sciences Center. Before the experiment was conducted, the accepted participants signed a consent form detailing the timeline of the experiment, the potential health risks of their participation, information about result and data confidentiality, and the contact information of the lead researcher, Sarah Nabong. Those who were physically unable to exercise, at risk of injury, or individuals who had a known health condition that could be exacerbated were asked not to participate in the study. Additionally, participants were asked prior to acceptance if they have taken any introductory course on macroeconomics. Students who stated they have not taken any introductory course in macroeconomics were then invited to participate in the study. This was pertinent as the educational video being shown involved basic concepts and applications of macroeconomics. Any prior exposure or knowledge of the material risked jeopardizing the experiment. The participation of this study was entirely voluntary and those who chose to participate were not paid. Participants were divided into two groups: those sitting stationary and watching a Khan academy video and those riding a bike at 50-70 percent of their maximum heart rate while watching the same Khan academy video. The participants selected were divided into the two groups at random. This was done by using an online group generator. Each group was labelled with the letter A or the letter B. Participants that were assigned into group A were placed in the control group: sitting and watching the Khan Academy video, and participants that were assigned into group B were placed into the experimental group: biking at 50-70 percent of their maximum heart rate and watching the 5-minute Khan Academy video.

Procedure

Once each participant entered the lab room, the researchers gave them a detailed timeline of how each experiment would take place. The A group began by sitting comfortably at a table where they were first connected to the EDA BIOPAC equipment. This was done by attaching the EDA transducer to the dell computer and placing one drop of isotonic gel on each sensor cavity. One sensor cavity was positioned on the pad of the index finger and the other was placed on the middle finger. After the sensors were snuggly attached, data collection of the participant's EDA occurred for the entire duration of the experiment. In the first minute of the experiment, baseline blood pressure was taken with a battery-operated blood pressure cuff. In order to collect a blood pressure reading, the cuff was wrapped snuggly around the upper arm just one inch from the participant's elbow and the black stripe within the cuff was aligned with the brachialis artery. When the cuff inflated, the participant's arm was resting on a table while they remained seated stationary. The cuff produced two values that were recorded: the systolic and diastolic blood pressures of the participant. After the blood pressure was taken, a pulse oximeter was placed on the participant's finger in order to measure heart rate. Measurements of the participant's heart rate were recorded in one-minute intervals throughout the experiment. Once three minutes had passed after connecting the pulse oximeter, the participant began watching the macroeconomics Khan Academy video. After the video concluded, the participant had their blood pressure taken again. Once the final measurements were collected, the participant was disconnected from the BIOPAC equipment.

Before starting the experiment for the B group, the target heart rate zone of 50-70 percent of each participant's maximum heart rate had to be calculated. This was done by subtracting their age from 220 and multiplying that number by 0.5 and 0.7 to get their personal ideal heart rate range for this experiment (Mayo Clinic). Once that was calculated, the participants were fitted for comfort on the stationary bike and a pulse oximeter was placed on one of their fingers to measure their heart rate for the duration of the experiment. Before they began biking, their baseline blood pressure was recorded. Additionally, at this time the participant will be connected to the EDA BIOPAC. All baseline measurements were done with the same procedural method as the A group. The participant then was asked to begin biking at a rate that allowed them to maintain their 50-70 percent maximum heart rate level. Once, the target heart rate range was reached, they were asked to maintain that for 2 minutes while EDA data was taken. During that time, three heart rate measurements from the pulse oximeter were recorded at 1 minute and 2 minutes from the start of cycling. If the participant were fatigued during the cycling, they were asked to reduce their speed to a more moderate pace. The allowance of the heart rate reduction would be noted during our analysis of the results. After those two minutes, the participants were instructed to watch the Macroeconomics Khan Academy video while maintaining their cycling speed. Again, during that time EDA data was being collected and heart rate was taken after every minute of cycling. Immediately after the video was stopped, the participant was instructed to stop cycling and blood pressure, heart rate, and EDG measurements were collected again. After all final measurements were collected, the participant was disconnected from the BIOPAC system and the data was organized in preparation for analysis.

Exactly one week after watching the video, the participants answered a six-question online survey that was sent to their student email. The questions were comprised of multiple-choice questions to test how well each participant comprehended the video. Once the experiment was completed, questionnaire results, heart rate, blood pressure, and data from the EDA on BIOPAC were all recorded in order to identify differences between the experimental exercise group and the stationary group. Single Factor ANOVA tests were performed in order to compare the means of the two groups for Blood Pressure, Heart Rate, and EDA. P-values <0.05 were interpreted to be significant.

Positive Controls

Prior to the initial events of the experiment, the researchers needed to test the efficiency and functionality of the BIOPAC equipment and test how well their procedure could be carried out. In order to test the EDA BIOPAC equipment, the researchers did positive control tests on themselves in order to determine if the equipment was able to detect changes in skin conductance. The researchers placed one drop of isotonic gel to each sensor cavity of the transducer and then wrapped one sensor around the index and the other around the middle finger of the person being tested. The positive control tests showed increased activity when biking, but an even greater spike when watching the video and biking. Another test carried out was for blood pressure. A battery-operated blood pressure cuff was applied one inch above the elbow and the white plastic marker in line with the brachialis artery. The researcher sat with their arm relaxed on a table while the cuff was inflated to take their baseline systolic and diastolic blood pressure measurements. One blood pressure reading was taken with no prior physical activity and one reading was taken after 10 minutes of moderate exercise to ensure there would be differed readings during the experiment. The final parameter tested was heart rate. In order to measure resting heart rate, a pulse oximeter was placed on the researcher's finger to detect their heart's beats per minute. Once that was tested, the researcher then attempted to maintain their 50-70 percent maximum heart rate range for 10 minutes, to ensure that it was physically achievable to do during the events of the experiment for the participants. If the participants are unable to achieve the desired heart rate range comfortably, EDA, heart rate and blood pressure data will still be collected for the participant, but it will be noted they were not able to achieve the desired heart rate range when reporting results.

Negative Controls

To establish a negative control, data for heart rate, blood pressure, and EDA were recorded for one group member. This was used to measure physiological parameters for periods of no experimentation or variable manipulation. This was then compared against two experimental baselines: one when the participant remained stationary and watched the educational video and one when the participant was physically active and watching the educational video. This comparison served to minimize any discrepancies in data analysis and showed that the BIOPAC system could reliably and accurately measure the sought out physiological conditions being tested.

Results

Participants

A total of 50 participants were used in this study. They were mostly students in Physiology 435 at the University of Wisconsin-Madison with two teaching assistants who participated. The participants were composed of 29 females, 20 males, and one who opted not to answer. Their ages ranged from 20-23 years old with an average of 21.4 years of age. There were

25 participants in each group. Because of inaccurate data collection and a change in procedure in the beginning of the study, a total of 10 participants data was omitted.

Blood Pressure

Blood pressure was taken before and after participants watched the Khan academy video in order to compare baseline levels to blood pressure at the conclusion of the experiment. Figure 6 shows the average diastolic blood pressures for each group before and after watching the video. For group A the average diastolic blood pressure prior to the video was 74.8 mmHg and average diastolic blood pressure at the conclusion of the video was 72.8 mmHg with a variance of 118.03 and 189.11 respectively. For group B the average diastolic blood pressure before the video was 76 mmHg and the average diastolic blood pressure after the conclusion of the video of the study was 75.2 mmHg with a variance of 97.65 and 89.7 respectively. The average change in diastolic blood pressure was greater in group A (1.98 mmHg) than with group B (0.68 mmHg). The calculated P value for group A was 0.6 and the calculated P value for group B was 0.82.

Figure 5 shows the average systolic blood pressures. For group A, the average systolic blood pressure prior to the video was 113.7 mmHg and the average systolic blood pressure at the conclusion of the video was 110.1 mmHg with a variance of 381.9 and 385.1 respectively. For group B the average systolic blood pressure prior to the video was 112.7 mmHg and the average systolic blood pressure at the conclusion of the video was 117.4 mmHg with a variance of 210 and 181.3 respectively. The calculated P value for group A was 0.59 and the calculated P value for group B was 0.31.

Heart Rate

For group A, the average heart rate before watching the video was 79.7 beats per minute (bpm) with a variance of 205.1. At the conclusion of the video, the average heart rate was 79.3 bpm with a variance of 171.1. The calculated P value was 0.80.

For group B, the average heart rate before watching the video was 109.2 bpm with a variance of 103.8. At the conclusion of the video, the average heart rate was 116.9 bpm with a variance of 74.2. The calculated P value was 1.89E-11.

Electrodermal Activity

EDA data was obtained using the BIOPAC tool. Figure 4 shows the average changes in EDA in each group. Participants from group A had an average value of 1.249 as a baseline, with a median of 0.5609, and standard deviation of 2.3448. During the video, Group A had an average value of 1.07, with a median of 0.53 and standard deviation of 2.03. The average difference between group A's baseline and during the video was 3.031, with a median of 0.80 and a standard deviation of 0.32.

Group B had an average value of 2.943 for their baselines, with a median of 0.70 and a standard deviation of 3.53. During the video, Group B had an average value of 3.03, with a median of 0.80 and a standard deviation of 3.60. The average difference between group B's baseline and during the video was –0.0088, with a median value of –0.02 and a standard deviation of 0.35.

Due to limitations in the BIOPAC system there was a lack of variance in each group. The calculated p-value that compared the differences between the baselines and final values between group A and B was calculated to be 0.016.

Questionnaire

Group A on average received 6 points out of 10 possible points with a variance of 2. Group B on average also received 6 points out of 10 possible points with a variance of 2.83. The p-value calculated between group A and B was 1.

Discussion

The goal for this study was to determine if moderate physical activity would increase participants' ability to remember and comprehend the Khan academy video that was shown. The only significant result we observed was elevated EDA of group B over group A.

We demonstrated that there was an increased sympathetic nervous system response using EDA due to the participants undergoing moderate physical stress. Although the relationship between physical stress and SNS response was shown, there was no significant difference in performance on the questionnaire between groups.

There are many external factors that may have influenced our data. One factor was inconsistent usage of the equipment. This included not using the same equipment for each participant and differences between each researcher's methodology. Many of the participants also seemed indifferent to the video presented which may have affected their overall engagement in the study. Another source of error came from the participants not completing the questionnaire exactly one week after the study took place. Due to the variance in time between the moment of encoding and the assessment, some participants were asked to retrieve memories across longer durations. A longer retention time would likely result in lower performance scores on the questionnaire. Also, some feedback from participants stated that the wording of the questionnaire was confusing. Additionally, some participants failed to read the directions at the beginning of the questionnaire. All these factors may have led to an excess of incorrect answers.

Future studies on the correlation between moderate physical activity and memory and comprehension can be improved by gathering a larger sample size, using newer equipment, and utilizing researchers with a more accurate and uniform method of data collection. If studies wish to analyze a more holistic view between exercise and memory, using an electroencephalogram (EEG) would be a more accurate representation of brain function. EEG provides measurements for brain wave activities, which may give a better insight into processes involved in memory and comprehension.

Much of the time in scientific literature, the focus was on how emotional stress can affect cognitive ability. This left a gap that we believe we have helped fill, that being how physical stress can impact the functions of memory and comprehension. Since our research is based on ensuring that the sympathetic nervous system is activated, this area of study is relevant in every unit of this course. Each unit in this class has delved into how the sympathetic nervous system affects different components and processes in the body. This course focused on many mechanisms of the sympathetic nervous system, which laid out the foundation for exploring sympathetic physiology in a context that piqued our interest. Because of that, we were able to apply the knowledge gained to our everyday lives. We hope that this study can inspire further Physiology 435 students to not be afraid to pursue the research that is pertinent to them.

Figures and Tables

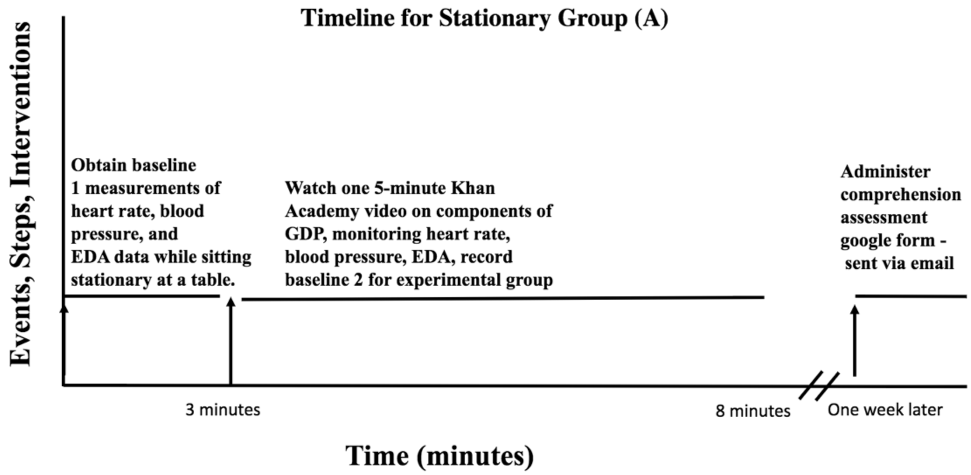


Figure 1: Experimental Timeline for Group A. This timeline begins after the participant has read and signed the consent form. The entire duration of the experiment for this group is about 8 minutes. It begins with baseline measurements that include blood pressure and an initial heart rate. The EDA is also attached to the participant at this time. The script may be read before and during baseline measurements. Once baselines have been taken, the video is started. While the video is playing, EDA and heart rate are monitored and recorded. After the video is over a final blood pressure is taken. One week after the study, the participant is asked to complete a post-participation survey via email.

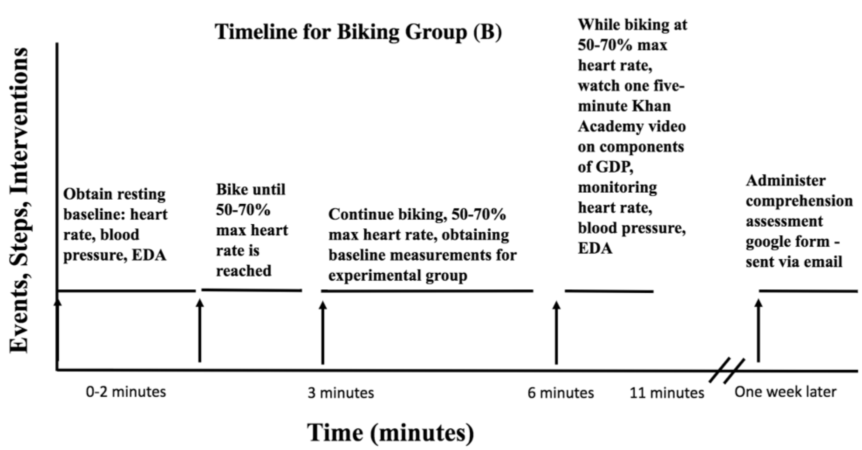


Figure 2: Experimental Timeline for Group B. This timeline begins after the participant has read and signed the consent form. The script is read at this time. The entire duration of the experiment for this group is about 11 minutes. It begins with initial measurements that include blood pressure and an initial heart rate. The EDA is also attached to the participant at this time. The participant is then asked to start biking and once the target heart rate zone is reached, baseline EDA and heart rate are monitored and recorded. After baselines have been taken, about three minutes, the video will begin. While the video is playing, EDA and heart rate are continued to be monitored and recorded. After the video is over a final blood pressure is taken. One week after the study, the participant is asked to complete a post-participation survey via email.

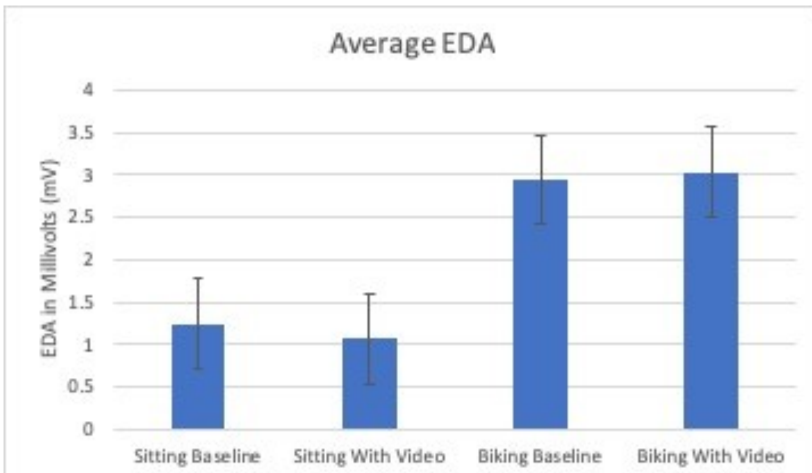


Figure 3: This figure shows the average EDA values, in millivolts (mV), of each group, during each part of the experiment.

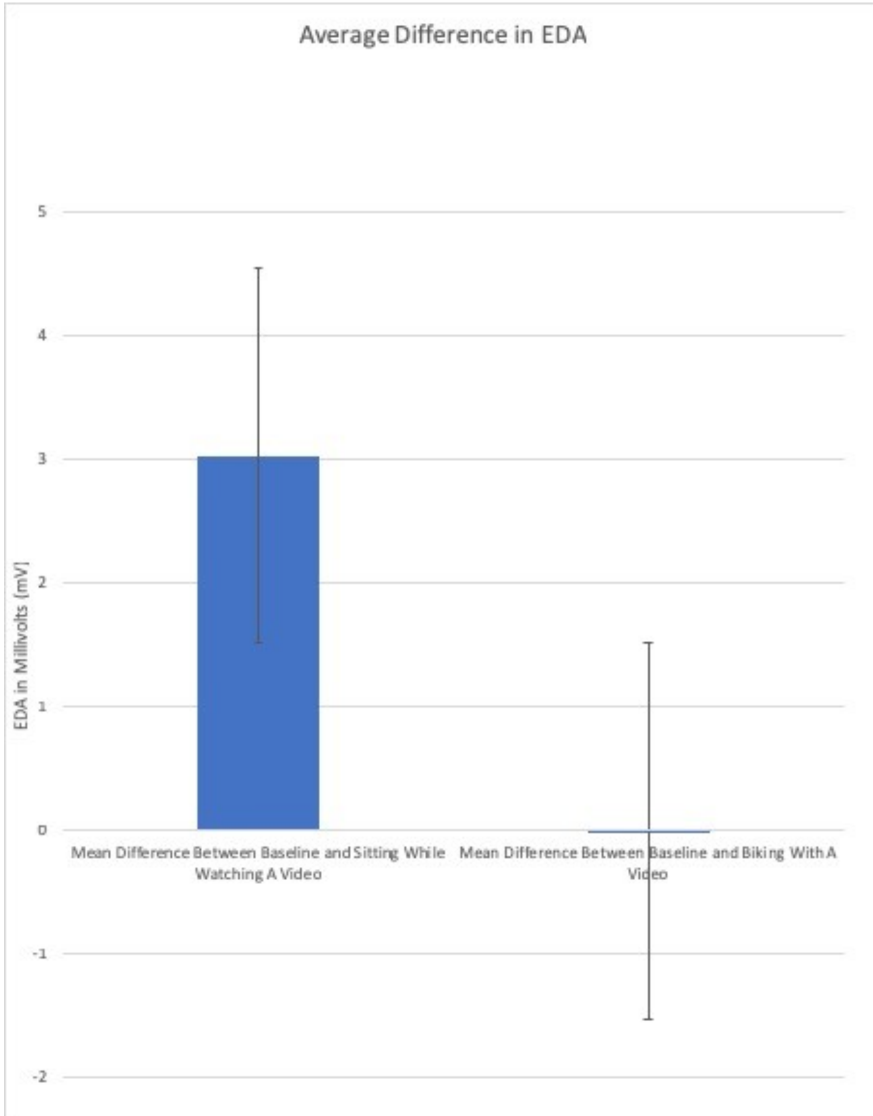
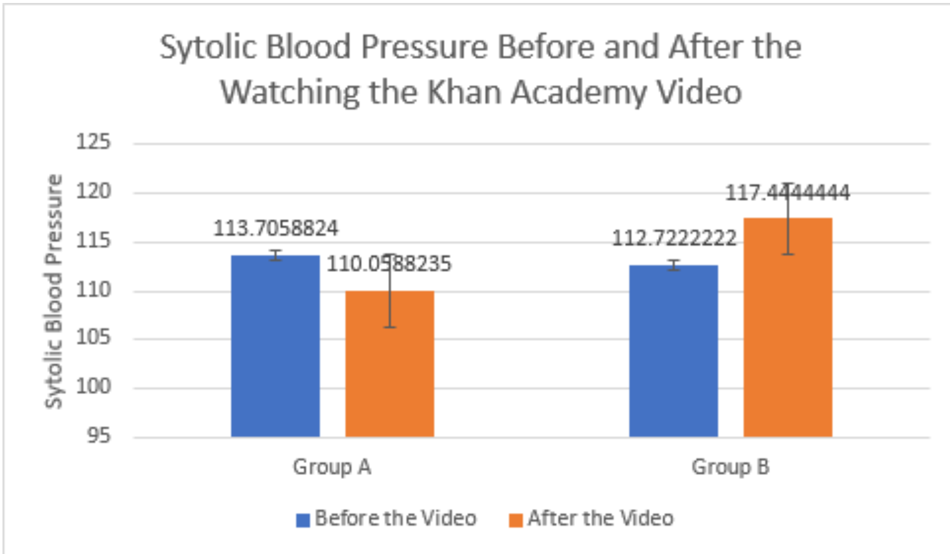


Figure 4: This figure shows the average difference of EDA values between baseline measurements and measurements during the video, for each group.



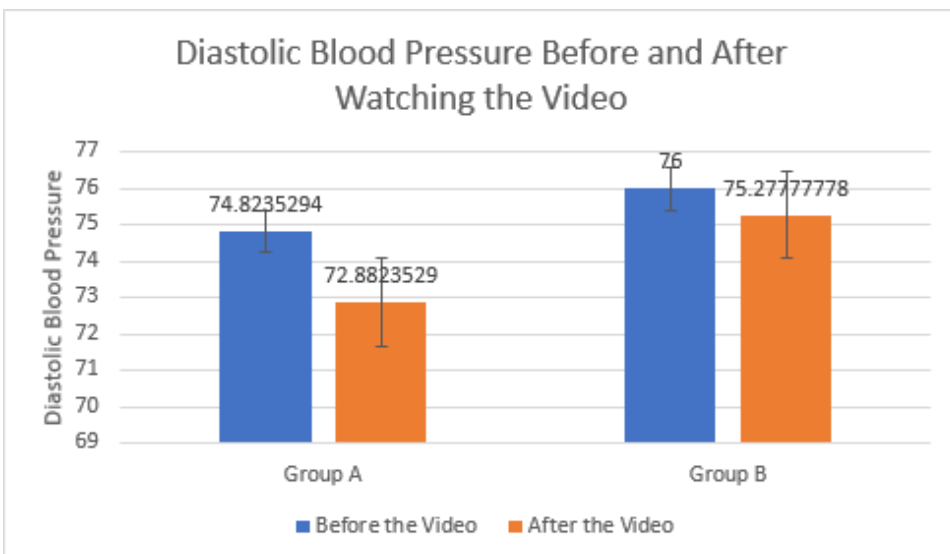


Figure 5 and 6: These figures show the systolic and diastolic blood pressures before and after watching the video, for each group.

Summary Raw Scores

Groups	Count	Sum	Average	Variance
Stationary (A)	13	78	6	2.83333333
Biking (B)	11	66	6	2

Table 1: This table shows the Raw Scores data for the two groups.

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0	1	0	0	1	4.3009495
Within Groups	54	22	2.45454545			
Total	54	23				

Table 2: This table shows the ANOVA results for Between Group variation and Within Group variation.

Appendix A

Experimental Script A

For this experiment you will be sitting stationary and will be asked to watch a five-minute video about economics. You will be hooked up to an EDA for the duration of the study. Your blood pressure will be taken in the beginning as a baseline measurement and at the end of the study. Your heart rate will be monitored and recorded periodically throughout the study. The video will begin after baseline measurements have been collected. At the conclusion of the video we will take the final blood pressure measurement and you will be free to go. In about a week after your participation we will email you a short post-participation survey. It is important that you fill it out one week from the trial. Thank you for participating in our study!

Experimental Script B

For this experiment you will be biking on a stationary bike and will be asked to watch a five-minute video about economics. You will be hooked up to an EDA for the duration of the study. Your blood pressure will be taken in the beginning as a baseline measurement and at the end of the study. Your heart rate will be monitored and recorded periodically throughout the study. The goal is to maintain 50-70 percent of your maximum heart rate, calculated based on your age. Someone will let you know when you are biking at the correct intensity to remain in the heart rate range. If at any time you feel that the exercise you are being asked to do is too exertive, let one of us know and you will be able to stop. The video will begin about two minutes after you have reached your heart rate zone; please continue biking for the entire duration of the study. At the conclusion of the video we will take the final blood pressure measurement and you will be free to go. In about a week after your participation we will email you a short post-participation survey. It is important that you fill it out one week from the trial. Thank you for participating in our study!

Appendix B

Participant Survey

Exercise induced sympathetic nervous system activation and its influence on memory and comprehension participation survey

This survey evaluates your level of retention and comprehension on the subject matter presented during the study. For each question please select ALL options that apply. Thank you for participating in our research.

Correct answers and point values are highlighted below. The survey consisted of five questions worth a total of two points per question, for a total of ten possible points.

Email Address:

1. GDP is...?
    a. The final production of services a country accumulates within a given period of time
    b. The final accumulation of foreign imports a country has within a given period of time
    c. The market value of all the final goods and services produced in a country in a given period (2 points)
    d. The final production of goods a country accumulates within a given period of time

2. The C in the expenditure equation represents...?
    a. Household spending (1 point)
    b. Consumption (1 point)
    c. Business spending
    d. Federal Reserve spending

3. Which of the following represented the expenditure equation in the video?
    a. Y = W+I+R+P
    b. Y = Households + Firms + Government + (Exports – Imports) (1 point)
    c. Y = I + C + G + NX (1 point)
    d. Y = Households + Firms + Government – Net Exports

4. Which of the following would not be added to the United States GDP for last year's spending?

a. Household spending of $500,000
b. Imports of goods valuing $200,000 from Mexico (1 point)
c. Government spending of $1.5 billion during 2017 (1 point)
d. All of the above would be included in last year's GDP

5. Which of these are involved in net exports?
   a. Purchasing 15,000 tons of bananas grown in Brazil (.5 point)
   b. Sending 5,235 tons of Wisconsin sharp cheddar to England (.5 point)
   c. Importing Cowboy boots from Texas (.5 point)
   d. Exporting Chilis from India (.5 point)

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