How do physiological responses such as respiratory frequency, heart rate, and galvanic skin response (GSR) change under emotional stress?

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Abstract

The human body exhibits different physiological responses to stress. One of these stressful situations includes when one is made uncomfortable or is possibly being deceitful, which is the physiological response that we were interested in measuring. In order to measure these changes, we devised an experiment in which we first asked participants ten baseline questions followed by ten experimental questions. We analyzed changes in galvanic skin response, heart rate, and respiratory frequency between the two sets of questions. The experimental questions were personal and potentially stress-inducing, intending to make the participant feel uncomfortable and stressed (the participants signed a waiver and were not harmed, nor was any personal information disclosed or recorded). We conducted this experiment on thirty participants, measuring these three physiological conditions before and while we asked them both sets of questions. We compared the measurements of the first ten control questions with the second ten experimental questions and found the mean and mean percent change of each. The p-values obtained from our data were as follows: galvanic skin response $p=0.0029$, heart rate $p=0.69$, and respiratory frequency $p=0.00024$. These results imply that the galvanic skin response significantly increased while respiratory frequency significantly decreased when participants were put under stress. The change in heart rate was not statistically significant. While the GSR results supported our hypothesis, the heart rate and respiratory frequency measurements did not. We believe our participants may have felt nervous, anxious, or stressed when we initially started conducting the experiment, skewing our heart rate and respiratory frequency control measurements. Another possible explanation is a physiological compensatory mechanism in response to stress. In order to counteract emotional stress, it is possible that respiratory frequency was decreased in an attempt to increase expiration time and increase acetylcholine release on the cardiac muscle, thereby decreasing unnecessary cardiac output.

Introduction

A typical polygraph test, or lie detection test, examines heart rate, respiratory frequency, and electrodermal activity (GSR) to produce a positive or negative result of deception. The two most widely used questioning techniques for a lie detection test are the Control Questions Test (CQT) and the Guilty Knowledge Test (GKT). Subjects of the CQT test are asked questions and must respond, often with "yes" or "no." (Ben-Shakar and Elaad, 2003). The physiological data are then analyzed and patterns are statistically modeled to determine whether or not the subject is lying. A pattern of greater physiological response to relevant questions compared to control questions leads to a diagnosis of deception. The CQT method has been critiqued as relying on improper control questions, therefore resulting in false-positives. An alternative polygraph procedure, the Guilty Knowledge Test (GKT), first presents the subject with a scenario and follows with a series of multiple-choice questions. Three answers to the questions are neutral responses unrelated to the scenario and the fourth response contains a detail included in the scenario. Physiological measurements are monitored when the subject is presented with the multiple-

choice questions. Polygraph tests that have used this questioning technique have shown a heightened response when the subject is presented with the relevant answer. One limitation of the GKT is that it can be used only when investigators have information that only a guilty subject would know (American Psychological Association, 2004).

We compared respiratory frequency, heart rate, and GSR measurements separately to see whether or not they changed significantly when the test subject was asked anxiety-inducing questions. We inferred that the first ten scripted questions would elicit a neutral response and the last ten scripted questions would induce anxiety due to the sensitive or controversial nature of each question. Galvanic skin response (GSR) describes the changes in the skin's ability to conduct electricity. GSR increases when the subjects secrete more sweat, as their skin is better able to conduct electricity. According to Kozel et al. (2009), GSR is a "primary channel" used in polygraph exams. Heart rate refers to the number of heartbeats per unit of time, expressed as beats per minute (bpm). Heart rate can vary based on many different conditions, including physical exercise, amount of sleep, stress, and many other factors (Engler et al). An electrocardiogram (ECG) measures the heart rate (beats per minute, or bpm) based on the heart's electrical conduction system throughout the body. The data appears in the form of beats per minute rather than a typical ECG recording because the Biopac ECG machine we used measures depolarization of the heart muscle and calculates heart rate data based on the time between each R peak, or each ventricular depolarization. The respiratory transducer (SS5L) records respiratory frequency using a belt which measures the force of chest expansion during each inhalation and exhalation. Heart rate, respiration rate, and GSR are all measurements of physiological processes controlled by the sympathetic nervous system that prepare the body for action and are generally considered as fight-or-flight responses to stress.

Hypothesis

If an individual is presented with personal, possibly stress-inducing questions, then a physiological response will be observed in GSR, heart rate, and respiratory frequency due to increased levels of stress. We expect for all three of these measurements to increase from initial baseline

measurements.

Materials

- Biopac Data Analysis Program

- GSR Transducer

- Electrocardiogram

- Respiratory Transducer

- List of Questions and Script

Methods

Thirty-one students enrolled at the University of Wisconsin-Madison between the ages of 19 and 26 participated in this study to measure the physiological response to deception and stress. All participants wore an SS5L respiratory transducer belt above the nipple to monitor breathing rate, three electrocardiogram (ECG) leads placed on the right wrist and left and right ankles to monitor heart rate, and a galvanic skin response device on the left index and middle fingers to monitor GSR. Biopac Student Lab Data Analysis program was used to record and analyze the data collected. Figure 1 depicts the experimental timeline for control and experimental groups.

The positive control group was constructed to elicit a physiological response in order to show that the GSR transducer, electrocardiogram, and respiratory transducer recognize a physiological response when there should be one. We recorded an individual's baseline measurements for 80 seconds before the individual did 40 push-ups, 40 jumping jacks, and ran 14 staircases. Immediately after this intense activity, heart rate, respiratory frequency, and galvanic response was measured for another 80 seconds. We followed the script outlined in the Appendix (Script 1). All of these devices were run through a single computer. Exercise produced an exaggerated, but similar physiological response to our predictions of how the body reacts under stress. The positive control also demonstrated that the equipment could accurately measure changes in physiological processes.

The other thirty individuals were selected for the experimental group (Table 2). We measured the

participants' baseline measurements of heart rate, respiration rate, and GSR by connecting them to the

ECG lead II, respiratory transducer, and GSR machine. The participants were then asked ten neutral

questions to serve as a negative control and ten experimental, potentially anxiety-inducing questions. One

experimenter monitored the Biopac Student Lab program while another experimenter read the

experimental script outlined in the Appendix (Script 2).

After the data was collected and compiled, Microsoft Excel was used sort and analyze the results.

We calculated the differences between the two mean values for each respective measurement and created

figures to illustrate differences in control and experimental heart rate, respiratory frequency, and GSR. A

paired t-test was conducted to obtain p-values between control and experimental values also using

Microsoft Excel. In this manner, we determined whether there was a significant difference in

physiological response between control and experimental question groups. Results were used to explore

and evaluate the correlation between stress and human physiological reactions

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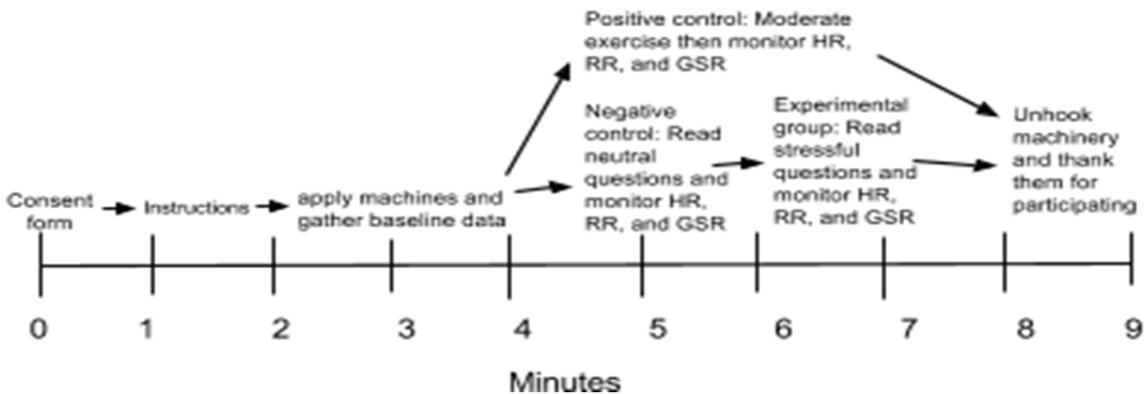
Figure 1. Experimental timeline

Results

Positive Control
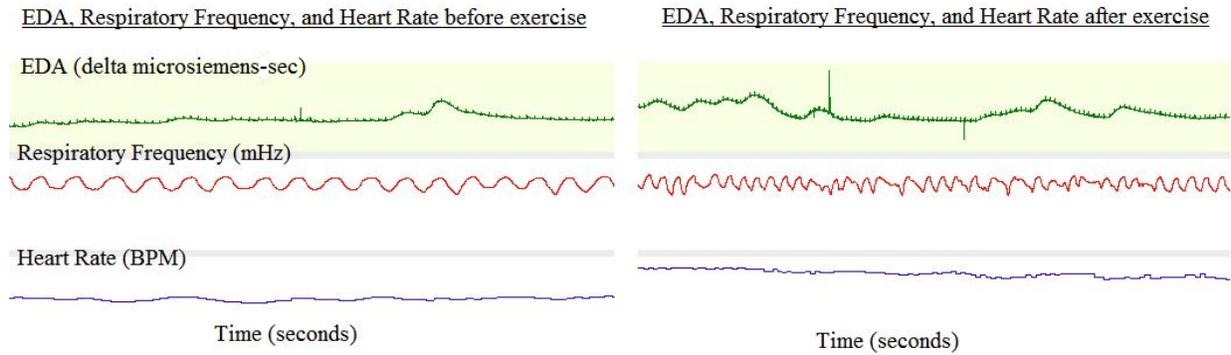
Figure 2. Positive control data

To confirm that a physiological response could be measured by the equipment used, we induced increased heart rate, respiratory frequency, and GSR response through exercise. As depicted in figure 2, the average galvanic skin response integral for the positive control before exercise was -5.6 delta microsiemens-sec and after exercise was 2.6. This is a change of 8.2. The average respiratory frequency measurement before exercise was 17.3 ventilations per minute (VPM) and after exercise was 18.4. This is a change of 1.1. The average heart rate measurement before exercise was 82.3 BPM and after exercise was 137.7. This is a change of 55.4. All of the positive control measures increased with exercise as predicted.
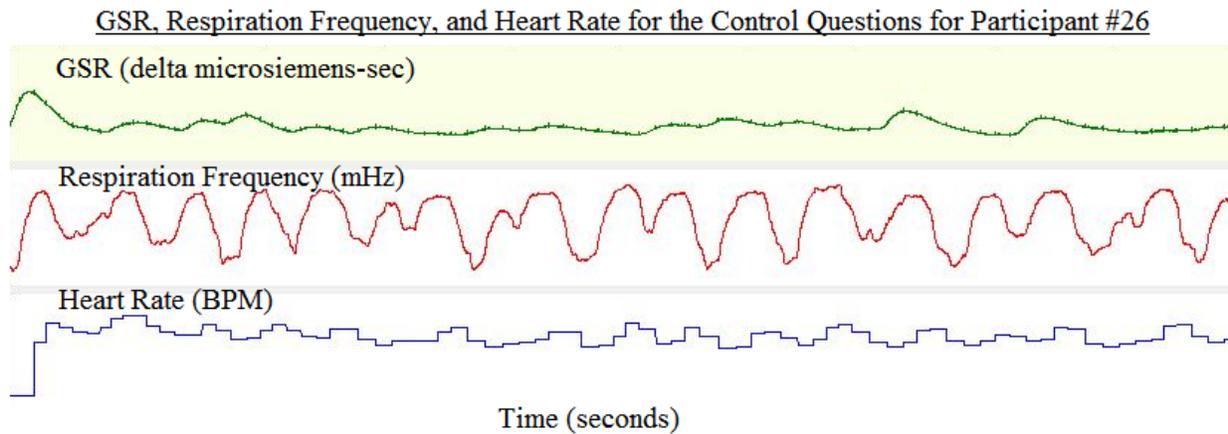
Figure 3. Negative control question sample data
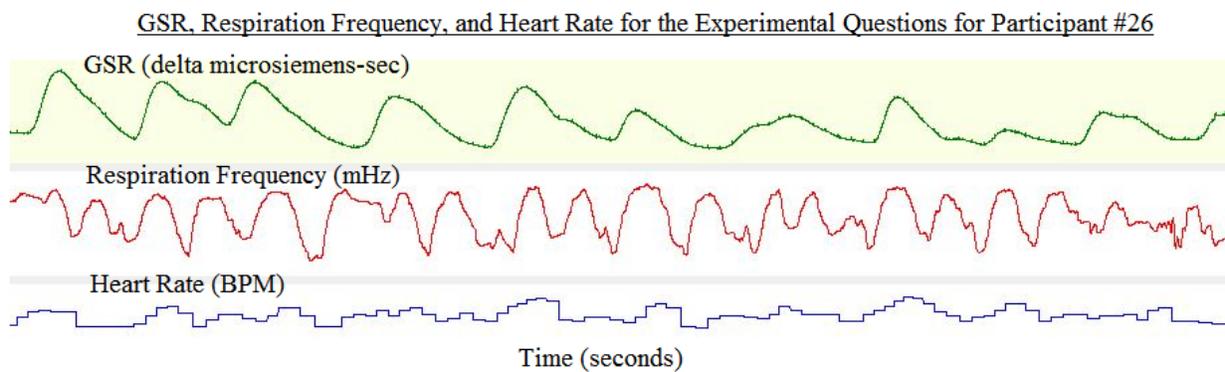
Figure 4. Experimental question sample data

Depicted above are a sample data set of the neutral negative control questions (figure 3), and the anxiety-inducing experimental questions (figure 4). Particularly of note is the GSR response. This participant had relatively little fluctuation in GSR response during the control questions, but high peaks with the majority of the experimental questions, indicating a heightened skin conductance response to anxiety-inducing questions.
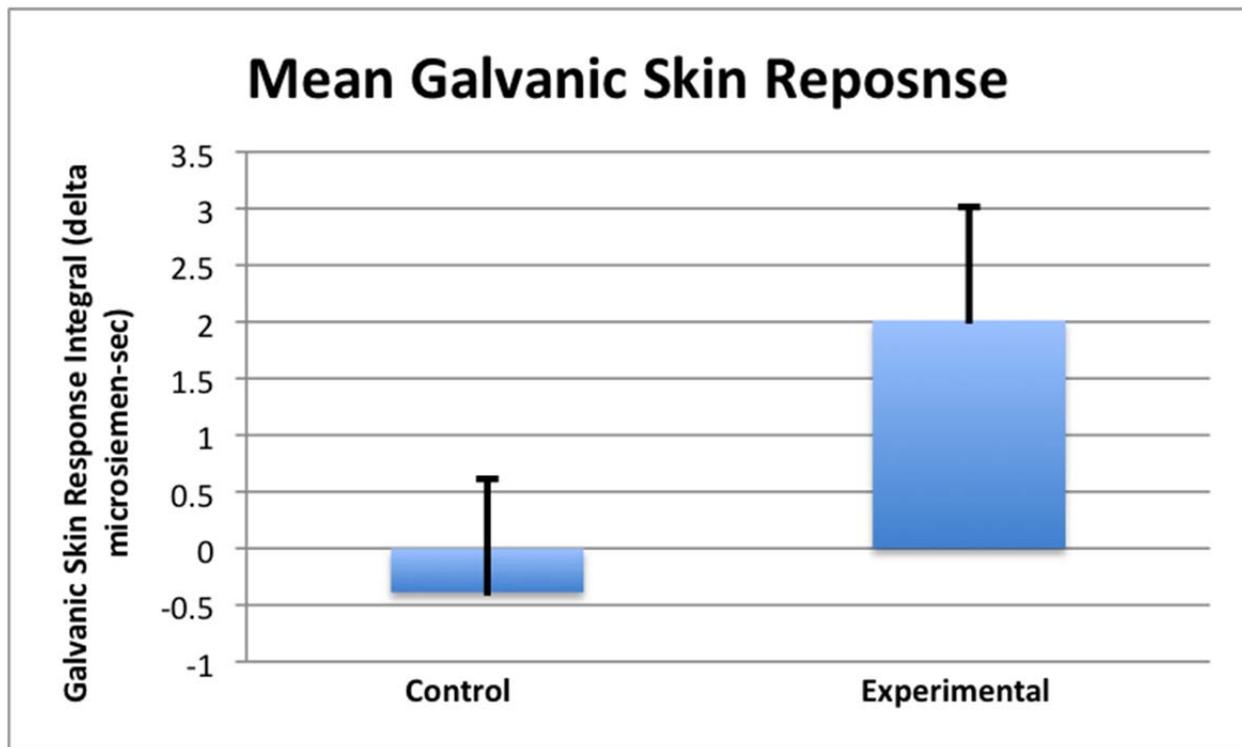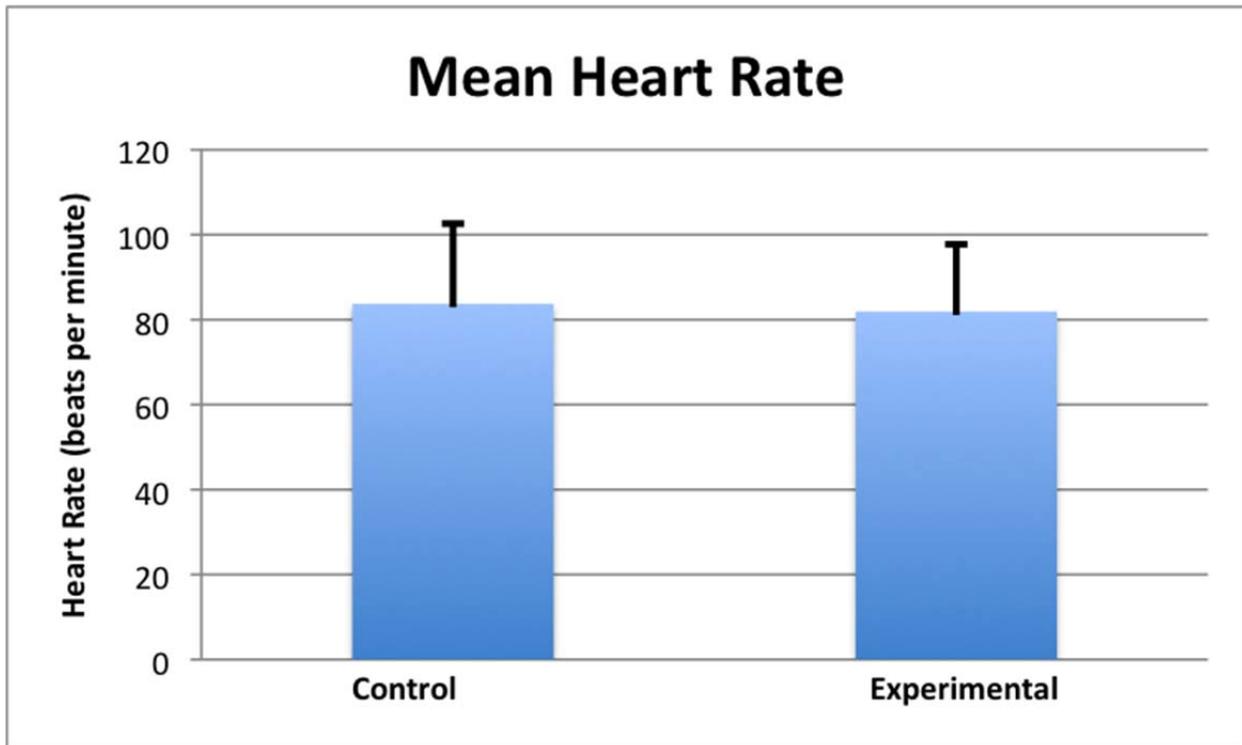
Figure 5. Mean control vs. experimental galvanic skin response integral

To measure an increase in emotional stress, we compared galvanic skin response between participants when they were asked neutral questions and anxiety-provoking questions. We calculated the GSR integral in order to account for large peaks in response to experimental questions, as seen in figure 5 above. The mean control integral for the thirty participants was -0.39±2.9 delta microsiemen-sec. The average experimental integral for the thirty participants was 2.01±3.1 delta microsiemen-sec. The change between the average control integral and experimental integral is 2.4. The p-value between the control and experimental integrals is 0.0029 and therefore significant.

Heart Rate

Figure 6. Mean control vs. experimental heart rate

We also compared measurements of heart rate while participants were being asked control questions and experimental questions. For the heart rate, the average control measurement for the thirty participants was 83.7±18.9 beats per minute. The average experimental measurement for the thirty participants was 82.9±15.8 beats per minute. The change between the average control measurement and experimental measurement is -0.82. Analysis of this data reveal that there is no statistical significance among the two conditions as the p-value is 0.69.

Respiration Frequency
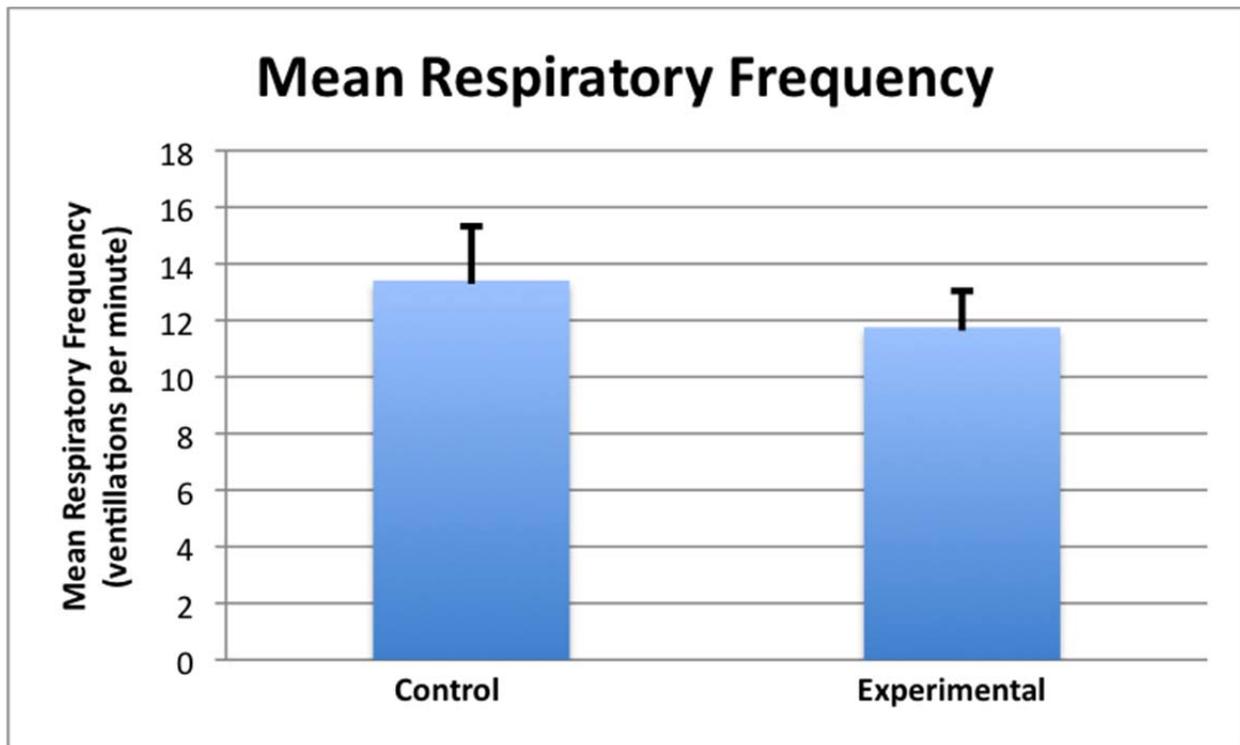
Figure 7. Mean control vs. experimental respiratory frequency

For the respiratory frequency, the average control measurement for the thirty participants was 13.4±1.9 ventilations per minute (VPM). The average experimental measurement for the thirty participants was 11.8±1.3 VPM. The change between the average control measurement and experimental measurement is -1.7. The p-value between the control and experimental measurement is 0.00024, and therefore significant. Each subject's respiratory frequency decreased during their response to anxiety-provoking questions compared to the neutral questions.

	P-value	Mean Control	Mean Experimental	Difference of Means	Mean Percent Change
GSR (delta microsiemen-sec)	0.0029	-0.39	2.0	2.4	2.3
Respiratory Frequency (VPM)	0.00024	13.4	11.8	-1.7	-0.12
Heart Rate (BPM)	0.69	83.7	81.9	-1.8	-0.01

Table 1. Summary table of mean control values, mean experimental values, mean percent change values, and p-values for each variable.

This table of p-values shows whether or not there is a significant difference in GSR, respiratory frequency, and heart rate between the control and experimental questions. We fail to reject the null hypothesis if the p-value is above 0.05 and reject the null hypothesis when the p-value is above 0.05. GSR and Respiratory Frequency showed a significant difference between the control and experimental groups while heart rate did not. The control mean, experimental mean, difference of means, and mean percent change are also presented above.

Discussion

Positive Control

We took baseline measurements of GSR, heart rate, and respiration frequency on a test subject. After this subject exercised, we measured these again. All three physiological measurements increased after exercise, demonstrating that it is possible to elicit responses in GSR, heart rate, and respiration frequency.

Negative Control

The first ten questions that we asked each of our thirty participants in our experimental group

served as a negative control, one that elicits no response. We were able to use these values as a baseline to compare our experimental results.

Galvanic Skin Response

How much one sweats impacts the moisture and electrical conductance of the skin. Since sweat is controlled by the sympathetic nervous system (Silverthorn, 2009), measuring skin conductance is a good indicator of physiological stimulation. The control questions were hypothesized to elicit less of a response and the experimental questions were meant to arouse the sympathetic nervous system, causing the participants stress and to sweat more. The galvanic skin response (GSR) readings measured the electrical conductance of the participants' skin before and during our experimental questions.

The GSR measured baseline integrals of our participants immediately after placement of the three measuring devices. This may have affected how nervous our participant was, and increased the GSR readings from normal levels, although this was not common. This may explain why some of the participants had a decrease in GSR when we asked them the experimental questions.

As expected, the data shows a significant change in GSR intervals between the control and experimental set of questions. The average response showed a high value of 2.4 delta mS/second, while the average response for the control questions was -0.39 delta mS/second (Figure 4). (The electrodermal activity was measured using the integral of the spikes. We think this is a better measure than the mean because it takes into account the range of data over all ten questions, including the maxima and minima, along with overall trends). A negative GSR means that the measurements fell below the original baseline measurements. The average percent change between these two was 2.3% showing that most people had a lot more conductance in their skin due to increased sweat response, which is a measure of physiological stress or discomfort (Kameia 1998).

The p-value obtained for GSR was 0.0029, which showed there was a significant difference between the control and experimental values. This supports our hypothesis that the experimental questions would increase participant anxiety and GSR integrals. However, the GSR test does not

necessarily show us when someone is lying, but rather when the questions stimulate an emotional response. This gives us better insight into how a polygraph test works and shows that the type of questions and order of questions are equally as important to the validity of the polygraph test.

Heart Rate

By comparing the average data between the control and experimental sets, we were able to measure the subject's change in heart rate. This change in heart rate may have been an indicator of an elevation of participant stress level. Initially, we expected that the participant's heart rate would increase when we started asking them experimental questions. Stressful situations are thought to trigger stress hormone release, which increase the heart rate (US News, 2012). For example, epinephrine is a stress hormone that acts to increase heart rate via its binding to beta-1 adrenergic receptors located at the SA node of the heart (Raff & Levitzky, 2011). However, our results did not agree with our predictions. The average percent change between the control and experimental questions was -0.012 (Table 1). It is possible that our experimental set up caused error in data collection.

Every time we conducted our experiment, we set up the machines to record information from our participants and then immediately started asking the first control questions. Our control data could be skewed because of this, due to the nervousness caused by the initial start of the experiment and not knowing what questions would be asked. For example, the average heart rate for people ages 18-25 years is 74 bpm (American Heart Association, 2011) and our data when our participants started the experiment was 83.7 bpm. This control heart rate is much higher than normal, but only slightly higher than the average heart rate during the experimental questions. While the average heart rate did go down by 0.82 beats per minute between the control heart rate and the experimental heart rate, the experimental heart rate was still at 82.9 (Figure 6).

For the experimental group and the control group to be significantly different from one another, the p-value needed to be at 0.050 or less. Since the acquired p-value for the control and experimental heart rates 0.69 (Figure 6), our statistic is insignificant. This result shows that there is not a significant

difference between the heart rate when the baseline questions were asked and when the experimental questions were asked.

Respiration Frequency:

Respiratory frequency was measured using a respiratory transducer belt. After analyzing the respiration rate data, we can reject our hypothesis that respiratory frequency would increase in response to anxiety-inducing questions. In fact, there was a significant decrease in respiratory frequency with an average decrease of 1.7 and a p-value of 0.00024 (Figure 7). Respiratory frequency and tidal volume can be under sympathetic or parasympathetic control. According to Houtveen et al. (2002), acetylcholine release from the cardiac vagal nerve onto muscarinic receptors in the heart increases during expiration and decreases during inspiration. Under parasympathetic control, the expiration phase is longer and therefore acetylcholine will dominate the cardiac muscle, slowing the heart rate. Under sympathetic control, epinephrine and norepinephrine from the adrenal medulla will act on the cardiac muscle beta-1 adrenergic receptors to increase contractility and therefore cardiac output (Levitsky and Raff, 2011).

Participant data showed a decrease in respiratory frequency for every participant between the neutral questions and the anxiety-inducing questions. While this finding opposes our hypothesis, there are several potential explanations for these results. One possible explanation for this could be due to participants being nervous when they first start answering questions. This might cause their breaths per minute to be at a higher frequency when they first start answering questions compared to towards the end of the experiment, the last ten questions. In order to determine if respiratory frequency truly decreases with stress or may have been influenced by other factors, we could have waited to take baseline measurements and begin the experiment in order to allow the participants to feel comfortable with the machinery. Reversing the question order also might alter the results.

Another possible explanation is a physiological compensatory mechanism in response to stress. The participant was not physically active during the experiment and therefore did not increase metabolic oxygen needs. Therefore, in order to counteract emotional stress, it is possible that respiratory frequency

decreased in an attempt to increase expiration time and increase acetylcholine release on the cardiac muscle, thereby decreasing unnecessary cardiac output.

Both of these explanations correspond with the heart rate data which also decreased overall from neutral questions to anxiety-inducing questions. However, the galvanic skin response measurements were significant for an increase in sweat stress response to the anxiety-inducing questions compared to the neutral ones. According to Sun et al. (2012), skin sweat activity is increased under mental stress. This suggests that the pathways under mental and physical stress are distinct for skin conductance versus respiratory frequency and heart rate. Further research into physiological reactions to different types of stressors including mental, emotional, and physical stress may improve understanding of autonomic pathways in response to different types of threats to homeostasis.

Further Discussion

We found that when presented with anxiety-inducing questions, subjects experienced a significant increase in GSR, a significant decrease in respiratory frequency, and no significant change in heart rate. Further study might include a similar study with slightly different design which may lead to a better understanding of confounding factors that may be influencing the physiological response. Additionally, more study could be useful to further investigate the link between GSR, respiratory frequency, and heart rate in response to different types of stressful or relaxed stimuli.

Although we had some issues with the participants being nervous in the beginning of the experiment, which decreased the mean change or reversed it to what we expected, we believe reversing the question order may have altered the data in a more extreme manner. We intentionally ordered our experiment so that we would obtain our negative-control values before our experimental data. If we had asked our questions in the reverse order, with the control questions being asked after the experimental questions, the participants would have been exposed to stress-inducing questions. This could have caused them to have an increased stress level while they had their control levels measured. These higher measurements could have made the control values larger than expected, giving a smaller percent increase

than was expected.

Future research in this area could produce more accurate results by having a more controlled environment and having the participants relaxed before we start the questioning. The experiment could be set up in a room away from any other people and could have had only one experimenter with the participants, decreasing their initial anxiety. The participants could be hooked up to the equipment and sit in a chair for a few minutes to make sure they were as calm as possible. Doing this would give a more representative view of a baseline control for each participant, which would give a larger percent change, better fitting our hypothesis.

Our experiment involved a fairly simple design, but still provoked a response in each subject according to GSR data. However, we could design a future experiment that involves a more complicated questioning strategy similar to the polygraph testing used in the Guilty Knowledge Test (GKT). This test would ideally produce more definitive results and show a clearer response to specific questions and stimuli. Ultimately, our experiment proved that anxiety elicits a physiological response, specifically changes in GSR and respiratory frequency. Therefore, we have evidence that the GKT and other similar tests that present a mentally or emotionally stressful stimulus provoke a significant physiological response and can feasibly serve as a tool to indicate deception or guilty knowledge (American Psychological Association, 2004).

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Acknowledgements

Appendix

Script 1. Prompt for Positive Control Test Subject

(Participant sits in chair, have them fill out the consent form)

Researcher: I will now hook you up to three different physiological measuring devices, we will measure your galvanic skin response, respiration rate, and heart rate.

(Hook up participant to GSR Transducer, Respiratory Transducer, and Electrocardiogram (WHITE=RIGHT wrist, RED=LEFT ankle, and BLACK=RIGHT ankle))

Researcher: We are now ready to start with the experiment. Please stay very still and do not speak unless answering a question. First we will take some baseline data. You will then perform several minutes of intense exercise. After you have finished, we will reconnect you to the machines and measure more data. If you do not have any questions at this time we will begin with the experiment.

(If participant has questions, answer them without giving too much away at what we are testing. After answering the questions of the participants, (or if the participant does not have any questions) proceed with collecting baseline data and then the exercise treatment, finishing by measuring patient data for one minute directly after exercise)

Script 2. Prompt for Negative Control/Experimental Group

(Participant sits in chair, have them fill out the consent form)

Researcher: I will now hook you up to three different physiological measuring devices, we will measure your galvanic skin response, respiration rate, and heart rate.

(Hook up participant to GSR Transducer, Respiratory Transducer, and Electrocardiogram (WHITE=RIGHT wrist, RED=LEFT ankle, and BLACK=RIGHT ankle))

Researcher: We are now ready to start with the experiment. Please stay very still and do not speak unless answering a question. I will ask you a series of 20 questions, please answer them as yes or no. If you do

not have any questions at this time we will begin with the experiment.

(If participant has questions, answer them without giving too much away at what we are testing. After answering the questions of the participants, (or if the participant does not have any questions) proceed to the question list and the participant all twenty of the posed questions. Wait 5 seconds after the participant answers the previous question before asking the next question).

Questions:
-Is it the year 2014?
-Are you male?
-Do you have a motorcycle?
-Is grass green?
-Are you currently a student?
-Does 1+1 = 2?
-Have you ever traveled to another planet?
-Are your eyes blue?
-Do you have any brothers?
-Did you eat lunch today?
-Do you think I'm good looking?
-Have you ever shoplifted?
-Have you ever cheated on a significant other?
-Do you know my race?
-Have you ever cheated on an exam?
-Have you slept with more than 5 people?
-Would you feel uncomfortable dating someone of a different race/ethnicity?
-Do you believe in God?
-Are you pro-choice?
-Do you think I'm overweight?

Table 2. Experimental Group:

Participant #	Gender	Age
1	Male	21
2	Female	21
3	Male	21
4	Male	22
5	Female	21
6	Female	21
7	Male	22
8	Female	20
9	Male	22
10	Male	21
11	Female	20
12	Female	21
13	Male	21
14	Male	22
15	Male	22
16	Male	21
17	Female	21
18	Female	21
19	Female	21
20	Male	20
21	Male	21
22	Male	21
23	Female	22
24	Female	22
25	Female	26
26	Male	20
27	Male	21
28	Male	23
29	Female	21
30	Female	21