The Somatic and Autonomic Nervous System's Response to a Fear Stimulus

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Abstract

The "fight or flight" response is an integral part of human physiology and survival that enables humans to engage in stressful situations. This incredible phenomenon promotes stamina and fortitude, encouraging increased attentiveness and ultimately continued existence. Its prevalence and potential in our lives has made it a frequently and extensively researched topic. Various studies have investigated the molecular mechanisms constituting a "fight or flight" response, and particular attention has been given to the procedure in which the sympathetic nervous system guides this response. What is lacking in the literature, and what this study investigates, is the probable influence the somatic nervous system has on this response. The somatic nervous system is measured via muscle contraction/tonus (Electromyogram, EMG), and the autonomic nervous system is measured via heart rate (Electrocardiogram, ECG) and finger perspiration (Galvanic Skin Response, GSR). Using a fear stimulus from an interactive game to provoke the "fight or flight" response in the subject, the before mentioned methods will measure/take real-time data. The autonomic response to a fear stimulus was strong and prolonged, as indicated by an increase in average skin conductance (p-value=6.49e-5, n=14) and average heart rate (p-value=1.06e-5, n=15) from before to after scare. In contrast to the autonomic response, the pre-scare and post-scare levels of muscle tonus and muscle contraction were not statistically different. Furthermore, there was a more prolonged autonomic response compared to the somatic response, as indicated by statistically significant differences in EMG to GSR (p-value=.0002, n=15 for EMG, n=14 for GSR) and EMG to heart rate (HR) (p-value=.0052, n=15 for EMG, n=5 for HR). From this, we conclude that the autonomic system dominates the "fight or flight" response, however the data is suggestive of a role played by the somatic system even though it is not statistically significant.

Introduction

One of the most profound human physiological responses that exemplifies the essence of survival is the "fight or flight" response to a stressful situation. Coined by W.C. Bradford in 1919, the fight or flight response is a rapid feed-forward mechanism that primes the body to react to something that is deemed a threat.[1] One of the hallmarks of the "fight or flight" response is the activation of the sympathetic nervous system, a division of the autonomic nervous system.[2] Physiologically, this response is characterized by increased heart rate and increased blood pressure among other cardiovascular changes. These aforementioned sympathetic physiological changes are under control of specific hormonal changes including increased epinephrine and norepinephrine secretion from the adrenal gland.[3] Upon external stress stimulation, the sympathetic response is rapid and far-reaching. Cardiovascular changes that occur during a "fight or flight" response have been illustrated in past literature to be the result of the autonomic sympathetic nervous system.

Other physiological effects observed during the "fight or flight" response such as increased muscle tonus, has not been shown to be a result of the autonomic nervous system. Muscle tonus is the residual muscle tension or continuous partial contraction of the muscle.[4] Muscle tonus is necessary at all times to prepare the muscle to contract. Moreover, increased muscle tonus is indicative of increased muscle preparedness, and upon stimulation results in a larger muscle contraction. Intuitively, changes in muscle tonus would be under the control of the somatic nervous system. A major component of the somatic nervous system is the control of skeletal muscle.[5] However, no literature has clearly elucidated which nervous system is responsible for the increased muscle tonus. With the assumption that muscle tonus is in part dependent on the somatic nervous system, our research looks to determine the importance of the autonomic nervous system on this physiological response.

It has been previously shown that once the external stimulus for the "fight or flight" response has been removed, the body eventually returns to its pre-threat state. This is the takeover of the parasympathetic autonomic nervous system.[6] The parasympathetic response is characterized by a decrease in heart rate, and blood pressure to a point at or near basal levels. However, there may be an increased basal or resting level compared to the pre-fight or flight levels. Furthermore, a second stress stimulus may illicit a larger fight or flight response due to this increased basal level.

The goal of our research is to not only confirm the expected physiological "fight of flight" response to an external stimulus, but also to help clarify the relationship, in terms of time and magnitude, between the somatic and autonomic sympathetic nervous system responses to a threat stimulus. Furthermore, we are looking to compare and contrast the relaxation response for both the somatic and autonomic system in hopes of finding a relationship between the two responses.

To compare the somatic and autonomic nervous systems by tangible measures, we will record heart rate and finger perspiration as a measure of the autonomic response and muscle contraction and tonus as a measure of the somatic response. To cause a fight or flight response, we will simulate a threat by means of a fear stimulus. Analysis will be done on the physiological responses to the threat. Recovery time will also be recorded for both the somatic and sympathetic nervous system.

We predict that the autonomic system response will be characterized by a sudden increase in sympathetic activity such as increased heart rate and increased skin perspiration. We predict that the somatic system response to an external fear stimulus will be characterized by a sudden increase in muscle tonus. Most importantly, we believe we will find interesting data that relates the somatic nervous system (muscle tonus changes) with the autonomic nervous system (cardiovascular changes). Furthermore, we think that muscle tonus will have a slow recovery time because the body slowly loses its anticipation for the need to react to some event. Furthermore, we expect the recovery time induced by the parasympathetic nervous system will be more gradual and prolonged compared to the sympathetic response.

Materials and Methods

To gain a clean reading for physiological responses, the subject washes their hands and wrists with soap and water then dries them thoroughly. They are asked to wear shorts and short sleeves. A designated research team member speaks with the subject throughout the experiment, explaining procedures. The subject sits on an elevated chair, legs dangling comfortably. Two different programs are run simultaneously on two computers. The iWorx program measures the galvanic skin response (GSR) and electrocardiogram (ECG). The Biopac Student Lab measures the electromyogram (EMG). BioAdhesive electrode patches are placed on the subject for the EMG and ECG, respectively. The locations of EMG adhesive electrodes are where the quadriceps connects to the knee (one toward inner leg, one toward outer leg), and the upper quadriceps near the hip socket, a total of 3 adhesive electrodes. ECG adhesive electrodes are put on both the right and left inner wrists as well as the right inner ankle, a total of 3 adhesive electrodes. Next, GSR Velcro strips are attached snuggly to the volar surface of the distal part of subject's pointer and ring fingers, on their non-dominant hand. The subject rests their hand on their thigh. The EMG is calibrated by measuring the thigh's electrical activity at rest for two seconds, and fully tensed for two seconds, to set the parameters for the Biopac system's measurements. Before the subject arrives, a maze game found on the Internet is opened on a third computer and expanded to the maximum screen size. All extraneous items on the screen are covered. The subject is told that they will first complete a practice round of the maze and that there are no time limits. Then the subject uses their dominant hand to control the computer mouse to guide the cursor through the maze. Recording begins by starting both programs and a stopwatch. Five (5) knee jerks are preformed to establish the starting knee jerk contraction. The subject is reminded to keep their body as still as possible during the experiment, and are instructed to begin the maze as soon as baselines for EMG, ECG and GSR are established. Baselines are established by making sure recordings are stable and relevant. The subject was instructed to complete four levels of the maze without constraint of time or accuracy. The third level, when the subject encounters a narrow section, requires increased attention and focus. We found that the test subjects would devote an increased level of attention toward the screen at the point just before the fear stimulus. The resulting fear response was significantly greater than any fear response that had been previously recorded or observed. The data analyzed and presented in this study are the measured responses elicited by using the interactive game as a fear stimulus.

The subject begins the maze. During the final portion of the maze, the startle stimulus appears on the computer screen. After this startle stimulus, the subject remains seated and still. Five (5) knee jerks are done and the subject remains seated with the equipment attached until the baselines are reached. The subject answers a brief survey regarding their anxiety levels and the experiment.

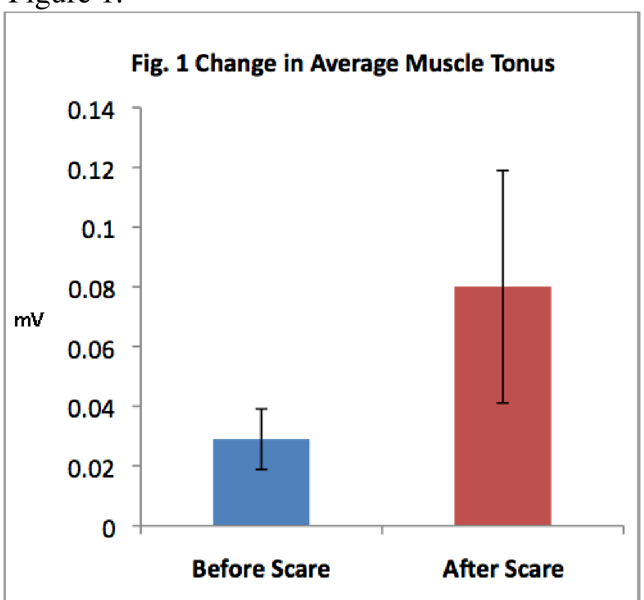
The GSR and ECG measure the autonomic response after a fear stimulus. The GSR records the skin conductance/moisture on the tips of the fingers, the electrodermal responses (EDRs). The GSR measurements taken/calculated include: baseline Skin Conductance Level (SCL), peak response SCL, change in SCL (baseline to maximum peak SCL), and time for SCL to return to baseline. All measurements by GSR were recorded as a graph of mV vs time. The ECG measurements taken/calculated include: heart rate both before and after the startle event, and the time to return to baseline heart rate following scare.

The Electromyography (EMG) and knee jerk response indicates the somatic response and show the muscle tonus. EMG measurements that we feel are appropriate are the peak to peak (p to p) of the muscular contraction from the knee jerk reflex both before and after the stimulus (mV), the standard deviation of the muscle tonus prior to and immediately following the stimulus (mV), and the time it takes for the increased muscle tonus to return to its original baseline (the before stimulus reading). The measurement of standard deviation is an appropriate means of measuring the muscle tonus since the signal oscillates around a mean value and p to p measurement would only give a maximum and minimum value in a certain time interval. Standard deviation gives an indication on average muscle tonus and the magnitude of the oscillations in mV of the EMG.

To analyze the data we will run multiple student t-tests to determine significance in our data. By comparing the data arrays for the time it took for each physiological response to return to baseline, we can assess whether there is a significant difference in time for each physiological response to 'relax.' We will also compare the average change (difference in value before and after scare stimulus) for muscle tonus, muscle contraction, skin conductance, and heart rate to identify which response incurs the most drastic response. We will be looking to find similarities and differences between the different physiological responses based on observation. The muscle tonus, muscle contraction, skin conductance, and heart rate before and after the stimulus will be compared to identify a significant change in the physiological responses. All statistical analysis will be done in Microsoft Excel.

Results

The effect on the somatic nervous system was measured by the electromyography and showed an increase in both muscle tonus and muscle contraction among the population of participants. The average muscle tonus (AMT) for the participants before the scare was 0.029 mV and the AMT immediately after the scare was 0.080 mV. The average muscle tonus before the scare, the baseline muscle tonus, was calculated based on measurements taken when subject first began maze until the time of scare. The amount of time elapsed, therefore, varies for each participant depending on the amount of time it took him/her to complete the maze. A student t-test between the two arrays was performed and did not show a significant difference (p-value=0.223; n=15). However, we feel confident that with a larger n value, the p-value would become significant. Data for average muscle tonus can be referred to in Figure 1.



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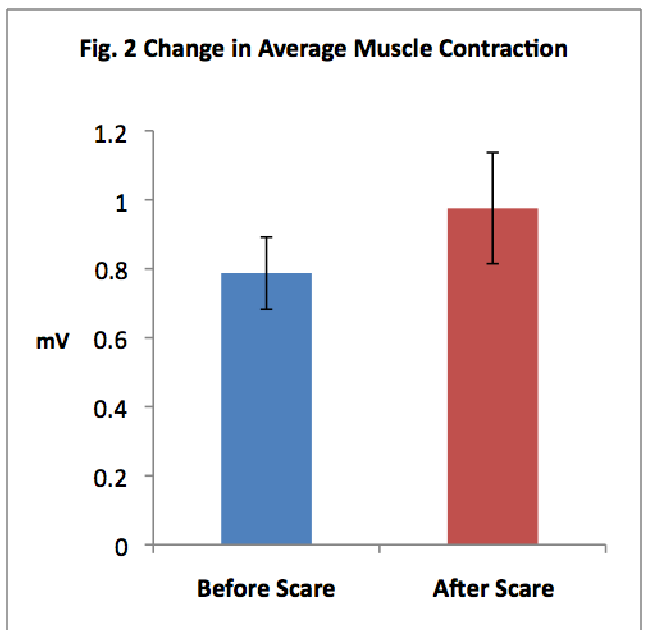
We also noticed that the average muscle contraction (AMC) before and approximately 10 seconds after the stimulus shows a difference (figure 2). The knee jerk reflex results in contraction of the quadriceps as indicated by one predominant peak on the EMG. From this we were able to calculate its height in mV. Pre-"fight or flight" contraction was calculated by averaging four knee jerk reflex peaks, which were generated immediately prior to beginning the maze, which is before the fear stimulus was applied. Likewise, contraction during "fight or flight" response was calculated by averaging four knee jerk reflex peaks generated approximately 10 seconds after the external fear stimulus was applied. Each knee jerk reflex was measured with approximately five seconds between each individual knee jerk, and this was consistent for each participant. These mean values of each participant were averaged together to give the average muscle contraction before the scare and after the scare for the population. Comparing these two arrays, the difference did not show significance but is suggestive since the AMC increased from 0.787 mV to 0.975 mV. With larger population, we feel confident the p-value would become significant (p-value=0.336, n=15).



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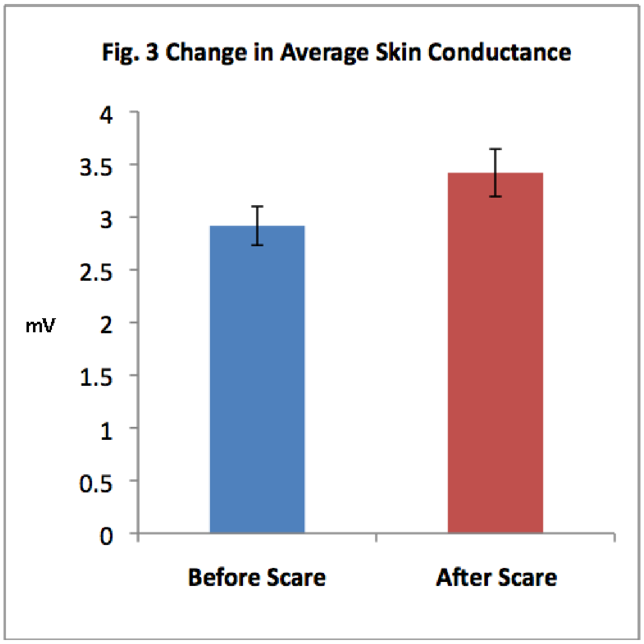
The effect on the autonomic nervous system was analyzed by the average skin conductance and average heart rate change before and after the stimulus. The skin conductance, being a measure of perspiration on the finger, increased when the fear stimulus was applied. There was a significant change in average skin conductance before and after the scare (p-value=6.490e-5, n=14). This is apparent in figure 3.

Measured by the electrocardiogram, the average heart rate (AHR) data also depicted a significant increase among the participants as a result of the fear stimulus (p-value=1.06e-5). The AHR before was 72 beats per minute (BPM) and 97 BPM after the scare. This data is presented in figure 4. Heart rate measurements were performed by manual calculating the number of peaks over a 10 seconds time interval. One measurement was calculated prior to the scare stimulus and, likewise, one measurement was calculated after the scare stimulus was applied.



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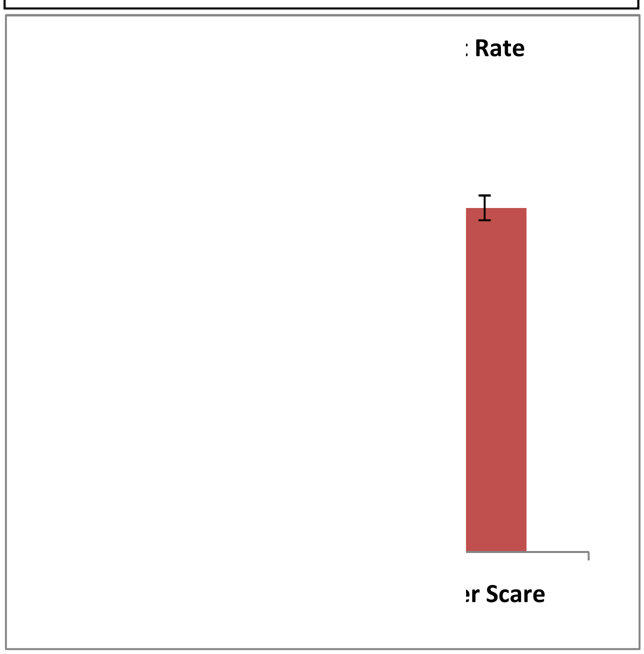

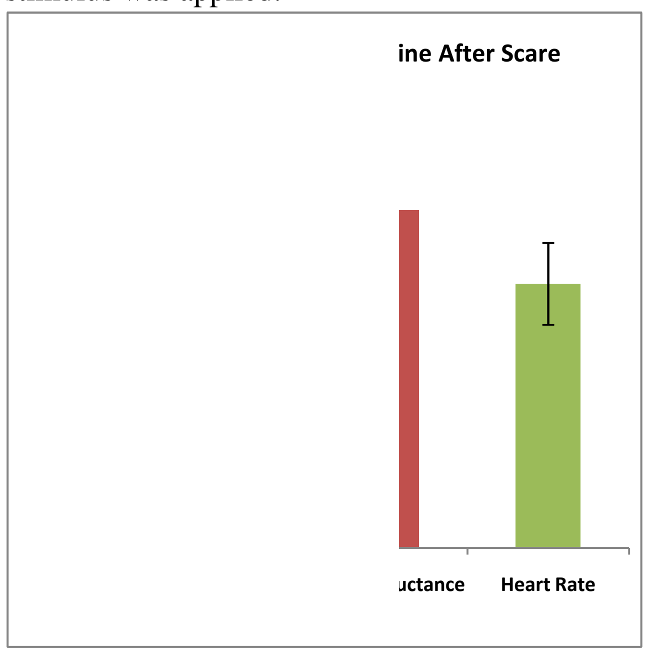

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Finally, we compared the relaxation response or time it took for peak measurements to return to baseline measurements for the EMG, GSR and heart rate. Note in Appendix I, the addition of the heart rate data from a preliminary study recommended by the reviewer. The population size for heart rate returning back to baseline was only five for this reason. The average time to baseline after the scare was calculated for the participants' muscle tonus (mV), skin conductance (mV), and heart rate (bpm). The result was a very significant difference in time between muscle tonus and skin response (p-value=.0002, n=15 for EMG, n=14 for GSR) as well as muscle tonus and heart rate(p-value=0.052, n=15 for EMG, n=5 for Heart Rate monitor). The average time to baseline for the muscle tonus was 6.7 seconds, average time to baseline for skin conductance was 61.9 seconds, and the average time for heart rate to return to baseline was 48 seconds. This data is shown in figure 5.

Discussion

Intuitively, and as presented in nearly every physiological textbook, the body's "fight or flight" response to an external fear stimulus is dominated by the autonomic nervous system. Contrarily, the somatic system, a nervous system characterized by cognitive/skeletal muscle interaction, has never been directly linked to the "fight or flight" response. In an attempt to further investigate this well studied phenomenon, we sought not only to reaffirm the existence of a strong autonomic response, but also to find existence of a somatic response to an external fear stimulus.

In this study, the physiological "fight or flight" response to an external fear stimulus was analyzed in terms of time and magnitude between the somatic and autonomic sympathetic nervous system. In addition, we sought to compare and contrast the relaxation response for both the somatic and autonomic nervous systems in hopes of finding a relationship between the two responses. The analyzed data supports the thesis insomuch as it clarifies the relationship of autonomic and somatic nervous systems with respect to time and magnitude.

Using changes in skin conductance and heart rate as indicators of the autonomic response, our data clearly supports, with statistical significance, the paradigm that the autonomic response to a fear stimulus is strong and dominant. Using changes in muscle tonus and muscle contraction as an indicator of the somatic response to a fear stimulus, our data is suggestive of a somatic response, however nothing can be concluded statistically. Moreover, not only was the autonomic response stronger than the somatic response, but it was much more prolonged. The appendix figure 1 illustrates the muscle tonus, skin conductance, and heart rate responses over time. It can be observed that the two autonomic responses seem to last much longer before returning back to the pre-scare baseline. We observed statistically significant data in which the somatic system returned to baseline at a much faster rate than the autonomic nervous system. In future studies, it may be possible to illustrate a more drastic and significant somatic response by using a larger population and a stronger fear stimulus. However, this finding is consistent with our understanding of the nature of the somatic nervous system having a rapid response rate. It is also consistent with the nature of the autonomic nervous system's more gradual response rate.

In a critical discussion regarding our methods, a number of problems arose throughout the experiment that should be addressed in future research. First and foremost, the sensitivity of the equipment, especially the ECG, and the violent nature of individual fear responses has disrupted several measurements immediately following the stimulus. Although heart rate was successfully determined, stretches of unreadable data could prove costly in the future. Related to ECG, the experimental setting caused the subjects to have a high resting heart rate due to the environmental stress of the monitoring devices, the difficulty of the maze, and scrutiny of observers. To overcome this, the subjects might be placed in a quieter room with a limited number of observers nearby. We originally anticipated that the program we were using would calculate the heart rate for us automatically, however it did not and manual calculations would have been far too time-consuming. Upon suggestion of the reviewer, we used a pulse oximeter to eliminate this problem, and also to determine the time it takes the heart rate to return to base levels after the scare stimulus. This allowed us to create an integrated timeline for the physiological responses to illustrate the relative temporal relationships. This can be seen in figure 1 of the appendix. The 5 additional subjects were included in all calculations and statistical analysis to expand the data. This data is included in figures 1-5.

Most importantly, future research must include a more comprehensive investigation of the somatic nervous system response after fear stimulus. This experiment only investigated one muscle of the somatic nervous system. Furthermore, our method of analysis (the knee jerk reflex) was subject to variability in the force and placement of the stimulation as well as the seated position of the subject. Our analysis attempted to control for these variables by taking a mean of the knee jerk response and discounting outlying extremes. Future groups would need a more objective and encompassing method of determining the somatic response to a fear stimulus.

References

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[2]Jansen, A. S. P.; Nguyen, X.V.; Karpitskiy, V; Mettenleiter, T.C.; and Loewy, A. D. "Central Command Neurons of the Sympathetic Nervous System: Basis of the Fight-or-Flight Response." *Science;* October 27, 1995: Vol. 270 no. 5236 pp. 644-646.

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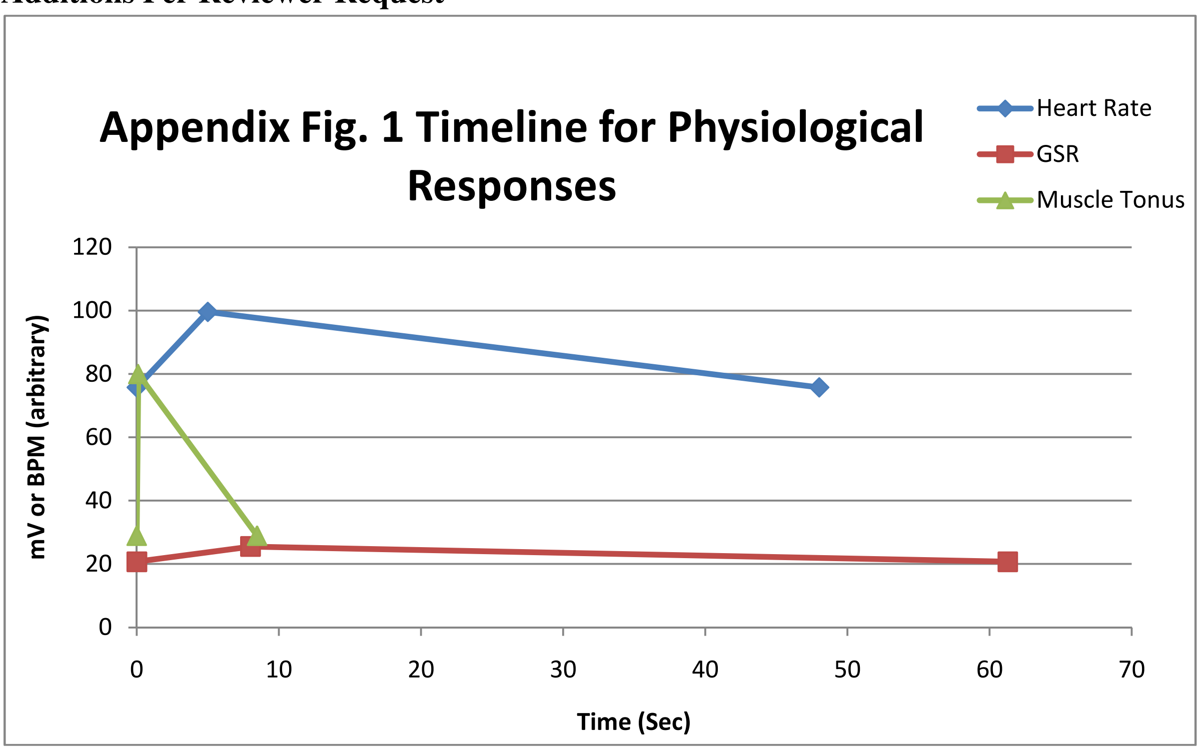
Appendix

I – Additions Per Reviewer Request



Appendix Figure 1 – This figure illustrates the temporal relationship between the heart rate, skin conductance and muscle tonus. The timeline starts at t=0 which is the time of the scare. The measurements at the scare are baseline measurements. The last data point indicates the average time for the physiological response to return to baseline.

II – First Draft Plus Reviewer Comments
III – Second Submission Plan
IV – First Submission Plan
VI – Consent Forms