

The Effect of Sympathetic Nervous System Stimulation on Skeletal Muscle Reflex Response Time

Anna Batley, Rebeca Cerda, William Dyke, Celena Ho, Abigail Moeller

University of Wisconsin-Madison

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Lab 602, Group 10

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Abstract:

The sympathetic response, also known as fight or flight, is a physiological response that occurs due to a perceived threat to survival. It can physiologically be observed through an increase in heart rate, respiratory rate, blood pressure, oxygen availability, and other mechanisms. In this experiment, we investigate if the fight or flight response induced by an auditory stimuli will quicken reaction time. Thirty participants completed a series of three mazes. A surprise auditory stimuli was played during the third maze to induce a fight or flight response. Throughout the completion of all of the mazes, the respiratory rate and heart rate were measured. After the completion of each maze, participants were asked to complete the Reaction Time Test, which measured response time. It was hypothesized that inducing a fight or flight response, which increases available oxygen and mobilization of energy stores for muscle contraction, would enable muscles to act more quickly resulting in a decreased skeletal muscle response time. A paired t-test with a 95% confidence interval was used to compare all three mazes where a significance criterion of $p < 0.05$ was significant compared to the baseline measurement. Maze 1 to maze 2, maze 1 to maze 3, and maze 2 to maze 3 had $p > 0.05$ indicative that the data did not have a significant difference. Overall, the reaction times were not shown to decrease despite an increase in respiration rate and heart rate among some participants indicative that there was a physiological change in response to the auditory stimuli. However, the physiological changes were not sufficient to cause a decrease in reaction times. Due to the lack of significance in reaction times, the null hypothesis cannot be rejected. Despite the lack of statistical significance, the data can be used to better understand the activation of the sympathetic nervous system, specifically the activation in respect to an auditory stimuli.

Introduction

Sympathetic nervous system stimulation increases heart rate, respiratory rate, blood pressure, and other mechanisms that contribute to a “fight or flight” response. The sympathetic nervous system is triggered in response to stressors that indicate danger, and its major components increase an organism’s ability to have a fight or flight response to that danger. However, it is unclear if the activation of the sympathetic nervous system actually leads to a quicker skeletal muscle reaction response time. Muscle reaction time is defined as “the time between the presentation of a sudden stimulus and the onset of a person’s motor response” (Schmidt & Wrisberg, 2008). In this study we test to see if increasing a person’s heart rate and respiratory rate leads to quicker skeletal muscle response times.

Stressful or startling situations elevate activity in the sympathetic nervous system as seen in multiple investigations. According to a study conducted on hypertensive rats by *Fischer L.D. et al*, there was proven to be a sympathetically driven increase in heart rate due to an air jet noise. This stimuli in turn stimulated an increase in epinephrine, norepinephrine, dopamine, and cortisol, which are key factors in the activation of the sympathetic nervous system (Fischer L.D., 1991).

In a similar experiment conducted by *Mahmood et al.* on the effect of noise on heart rate in humans, the conclusion was made that there was an increase in heart rate with exposure to noise (Mahmood, 2006). Noise is an important factor in fear and can have a large impact on sympathetic activation. In both the study done by *Mahmood et al.* on humans, and the study done by *Fischer L.D. et al* on rats, noise was the factor chosen to stimulate the sympathetic nervous system and activate that fight or flight response. Specifically, it is the amygdala that is stimulated

by fear upon hearing a scream or startling noise which induces the secretion of epinephrine (Akpan, 2015). Epinephrine, along with other hormones such as norepinephrine, dopamine, and cortisol, are important as they stimulate the sympathetic nervous system. Stimulation of the sympathetic nervous system allows heart rate, blood pressure, and breathing rate to increase, preparing a person for whatever stressful situation may be upon them.

In the central nervous system, the medulla oblongata in the brainstem contains the Vasomotor and Cardioacceleratory centers. Sympathetic stimulation of these centers causes the release of norepinephrine on the heart and blood vessels. Introducing this neurotransmitter causes blood vessels to dilate and more oxygenated blood to reach the muscle tissue due to faster heart rate which leads to greater cardiac output (Marshall, 1982). Additionally, increased respiration rate associated with a sympathetic nervous response increases oxygen available to muscle tissue in expectation of work (Your Lungs and Exercise, 2016). The sympathetic response also mobilizes energy stores through glycogenolysis, gluconeogenesis, and lipolysis, in part so skeletal muscle has enough available energy for contraction (McCorry, 2007). These studies show how the sympathetic nervous system induces processes that prepare muscles to do work, but they do not show whether the muscles actually respond more quickly than they otherwise would.

In our study we measured heart rate, respiratory rate, and skeletal muscle reaction time after a startling auditory stimulus was sounded. Due to a sympathetic nervous system response, we expect that participants' heart rate and respiratory rate would increase after the auditory stimulus, leading to faster reaction times. The purpose of this study was to determine if an induced sympathetic nervous response after a startling auditory stimulus would indeed decrease

skeletal muscle reaction times. We hypothesize that because a sympathetic response increases available oxygen and mobilized energy stores for muscle contraction, the muscles will be primed to act more quickly than they would without an induced sympathetic nervous response, and skeletal muscle response times will be faster.

Materials

The variables tested to display a sympathetic response were heart rate and respiratory rate. Heart rate was tested using a pulse oximeter and CO₂ detector (Model 9843, Nonin Medical Inc. Plymouth, MN) to measure beats per minute (BPM). Respiratory rates were measured using a respiratory transducer (Model: SS5LB, Biopac Systems Inc. Goleta, CA) with lung expansion and contraction data representing breaths per minute. To display skeletal muscle reaction times, we used the reaction time test on [humanbenchmark.com](https://www.humanbenchmark.com) (<https://www.humanbenchmark.com/tests/reactiontime/>). Biopac headphones (Model: OUT1, Biopac Systems Inc. Goleta, CA) were utilized to reduce outside noise and to play the startling sound to the participants. The recording and analysis of the data was conducted using Biopac Student Lab System (BSL 4 Software, MP36) on Windows 10 Enterprise operating system (OS build 15063.850). The Biopac Systems Inc. Student Manual was also used as a reference for equipment use.

To evoke a sympathetic response in the participant, a surprise scream sound (explained in procedure, <https://www.myinstants.com/instant/scream/>) was utilized interrupting the third of three written maze completion tasks. The mazes (printactivities.com) were used as a null distractive task. Participants were given a pencil to complete the mazes.

Methods

Procedure

The experiment took place at the University of Wisconsin-Madison with participants from the Physiology 435 course in Spring 2018. These individuals were asked to complete a consent form, which informed them of a potential increase in a sympathetic response. Each participant was then asked to sit in a chair without armrests, with their eyes closed, and relaxed breathing. For baseline measurements of respiration and heart rate to be taken, the BIOPAC Respiratory Transducer (SS5LB) was placed below the armpits and above the nipples of the participant with the tension tight to chest contraction. The index finger of the non-dominant hand was inserted into the Pulse Oximeter attached to the Carbon Dioxide Detector. The SS5LB and measurements were taken with the Biopac Student Lab System: BSL 4 Software. The Pulse Oximeter measurements were continuously recorded throughout the experiment using an iPhone (model). The reaction time measurements were tracked on the Reaction Time Test (humanbenchmark.com). This reaction time test had participants click on the mouse pad every time the laptop screen changed from red to green. Their reaction time was displayed on the screen after each click. The Reaction Time Test used a variable delay for the appearance of the visual stimuli with five separate trials between each maze. The five reaction times were then averaged for each post-maze period.

While still connected to the BIOPAC Respiratory Transducer (SS5LB) and the Pulse Oximeter, the participant was allotted one minute to complete the first maze. Breathing and heart rate throughout the mazes were measured continuously. Once the first maze was completed, the

participant completed the Reaction Time Test, and reaction times to visual stimuli were recorded.

A second maze was then administered to the participant, which they were again given one minute to complete. After the maze was completed, the five Reaction Time Test measurements were taken and averaged a second time. These first two mazes were given to elicit a skeletal muscle reflex response similar to that of the baseline measurements.

A third maze was given to the participant and one minute is given to be completed. Fifteen seconds after the participant has started the third maze, an investigator played the surprise sound through the participant's headphones. After this auditory stimulus was heard, the participant immediately began the Reaction Time Test to obtain reflex measurements. The startling scream sound was administered as a sympathetic stimulus to create a shorter reflex response time of skeletal muscle. After the completion of the final measurements, the investigator assisted in the removal of equipment from the participant.

Positive Control

The change in respiration and heart rate can be measured using the pulse oximeter and BIOPAC devices listed in the *Materials* section. Figures 1 and 2 show the respiration data of a group member both before and after the following activity stimulus. To induce a physiological response different from the resting state, the group member ran up and down five flights of stairs before respiration and heart rate measurements were taken. Comparing figures 1 and 2, one can see that the group member's respiration increased both in frequency and amplitude after the activity compared to the baseline measurements. Pulse Oximeter data was also affected by the activity. Before the group member performed the activity, pulse was 70 bpm. After the

performed activity, pulse was 123 bpm. This positive control data is evidence that physiological data such as heart rate and respiration could be measured both before and after a stimulus is applied.

Negative Control

For each participant, the physiological baseline of respiration and heart rate was measured by having a group member sit in a chair without armrests, with their eyes closed, and relaxed breathing for one minute.

Results

Subject Characteristics

A total of 30 subjects comprised of 7 males and 23 females with ages ranging from 19 to 39 participated in the experiment. The majority of the participants (27 out of 30) were students enrolled in Physiology 435 at the University of Wisconsin-Madison. Before the participants underwent testing, they all were asked to sign a consent form detailing the purpose of the experiment, physiological factors being measured, and potential triggers of the experiment. Participants had an option to opt out of participating in the experiment after reading the consent form.

Physiological Data Results

Subjects heart rate and respiration rate were- on average- shown to increase from the first and second maze trials to the third “scream” condition (Fig. 5a and 5b). However, there was no correlation with increased heart rate or respirations with faster response times in the reflex

response task (Fig. 5c.). For all figures we included the average values as well as the maximum and minimum values to illustrate the range experienced by participants.

Heart rate measurements from trials 1 and 2 compared to trial 3 produced p-values of .0268 and .0093 respectively using a paired t-test with an $\alpha=.05$, and a 95% confidence interval. This data shows that heart rate from trial 3 significantly increased from the two control trials.

Respiration rate was also significantly increased in trial 3 compared to trials 1 and 2. Using a paired t-test with a 95% confidence interval and $\alpha=.05$, the p-values were .050 and .046 respectively.

Two paired t-tests with 95% confidence intervals and $\alpha=.05$ were used to compare the magnitude of the difference in response times between trial 1 and trial 3, and trial 2 and trial 3. The t-test comparing the response times from trial 1 to trial 3 produced a p-value of 0.513. The p-value produced from comparing trial 2 to trial 3 was 0.129. Based on these p-values there is no significant difference in reflex response times from the control trials 1 and 2 to the “post-scream” trial 3.

Figure 6 compares the percent difference in averages for each trial tested from maze 1 to maze 2 and maze 1 to maze 3. The maze 1 trial is interpreted as the baseline measurement. The figure represents a decrease in all three variables tested from maze 1 to maze 2 and an increase in heart rate and respiration rate tested from maze 1 to maze 3. While reaction time decreased from baseline for both maze 2 and 3, it decreased less after the auditory stimulus compared to just a second “non-stimulus” test. Averages from Figures 5a-5c were taken and the percent differences between the maximum and minimum were found for each variable tested. 30 participants results

were averaged for each trial. The maximum and minimum value for each trial is shown in the graphs as well.

Discussion

Overall, it was determined that the data collected was not statistically significant. The purpose of our study was to determine if skeletal muscle response times would decrease after activation of the sympathetic nervous system by increasing heart rate and respiration rate. While we were able to evoke a sympathetic response in most participants, skeletal muscle response times did not decrease in response to the stimuli. There were no statistically significant decreases in skeletal muscle reaction times found. These findings provide evidence that a sympathetic nervous response does not reduce skeletal muscle reflex response times.

We believe there could have been a variety of factors interfering with the validity of the results. The method by which the data was collected and the objective of the study should remain the same, however the use of a more startling stimulus may have elicited a stronger response throughout more of the participants. After the startling stimulus was heard, there was a statistically significant increase in heart rate and respirations throughout the participants. However, a more startling stimulus may have potentially caused heart rate and respirations to further increase, leading to a stronger sympathetic nervous system response. This stronger sympathetic nervous system response may lead to different results of skeletal muscle reaction time.

Our results also may have been affected by participants having prior knowledge of our experiment before partaking in it due to communication from other students in the course. If

subjects had knowledge that there was a startling stimulus during the experiment, they may have been anticipating it in the process. Because of the anticipation, they may not have had quite as large of a sympathetic reaction to the sound as intended, therefore their skeletal muscle reaction times would not decrease as we had expected.

Looking at our experiment from a different perspective, our startling stimulus may have led to null results due to distracting the participants from the reaction task. After our startling stimulus played in the headphones, there were many different reactions from the participants. While some participants showed no noticeable reaction, others jumped in their chairs, and some even giggled and looked around the room confused. Immediately after the startling stimulus was played the participants were instructed to begin their third reaction test. Due to the unexpected stimulus, participants may have been distracted and therefore not as focused as previous trials as they began their last reaction test.

The reaction task we chose was a computer task in which the participants had to click the mousepad in response to a color change on the screen, and their reaction time in responding to the color change was automatically measured and averaged. Like stated above, a possible confound in our study may have been participant distractions due to the startling stimulus while doing the third reaction test. Because of the activation of the sympathetic nervous system in the participants, their focus on the computer task may have been hindered which could explain the increased reaction times. For future studies, developing a method to test reaction time in a more active manner may better encompass the reactions of the sympathetic nervous system.

It is important to note that before beginning the task, a brief explanation of how to do the reaction test was given to the participants, but the participants weren't able to practice the task

for themselves. Participant's reaction times decreased from trial 1 to trial 2 of the task, and this could be due to the possibility of a training effect. Completing this training and allowing the participant's to become more familiar with the task prior to starting may have led to clearer results in the study.

Researchers may also consider widening their range of participants as the majority of our contributors came from the Physiology 435 course in Spring 2018, which could have an effect on the preparation or expectations of the study they will be participating in. Students who completed this experiment as subjects may have conversed with Physiology 435 peers about the parameters and tipped off future subjects to the surprise stimulus. Comfort is also an important aspect to this study because we had two researchers in the room at a time with one participant. Acknowledging the concept of social facilitation, the procedure of this study could be altered in future studies by having researchers leave the room. The concept of social facilitation was studied by *Dashiell* where he found that participants' performance was either improved or impaired in the presence of evaluators depending on the task given to them (Dashiell, 1935).

Additionally, future studies and research on the sympathetic nervous system and skeletal response time could potentially benefit from testing response time using electromyogram (EMG), which can measure elapsed time to either a relaxation or contraction (Yotani 2014). An EMG may produce clearer results, as this measurement assesses the processing time of the nervous system, which could be useful in analyzing smaller differences in response time. Skin conductance and blood pressure are two other variables with potential to add useful data to the results. Skin conductance measures autonomic nerve responses, which would be useful in

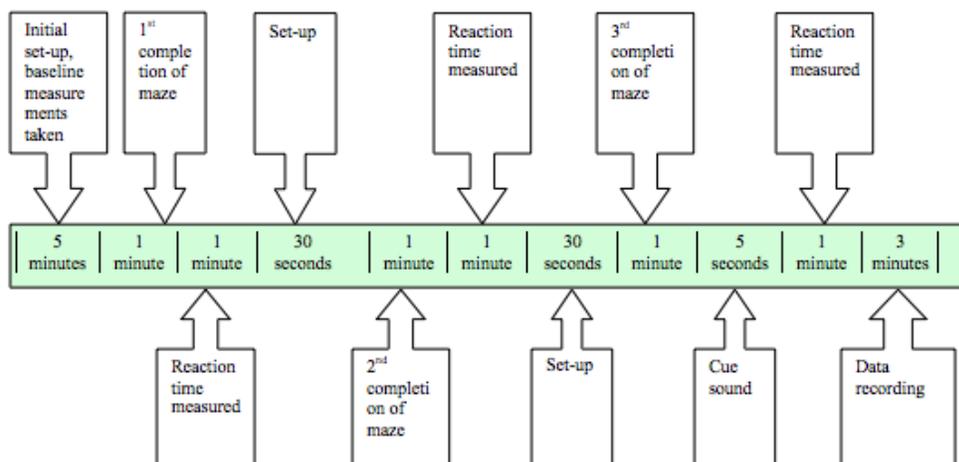
determining the impact of the auditory stimuli on the nervous system, while blood pressure would also give researchers a similar conclusion.

Conclusion

After analyzing our results obtained from this experiment, we failed to reject the null hypothesis. It was found that an auditory stimulation of the sympathetic nervous system did not make a statistically significant difference in reaction times. Our results show no relationship between increased sympathetic nervous response and faster skeletal muscle reaction time.

Timeline

Events volunteer will experience—using 20 minute time slots per participant



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Appendix



Figure 1. Respiration data of person at rest



Figure 2. Respiration data of person after activity



Figure 3. Heart rate data of person at rest



Figure 4. Heart rate data of person after activity

Average Heart Rate by Trial

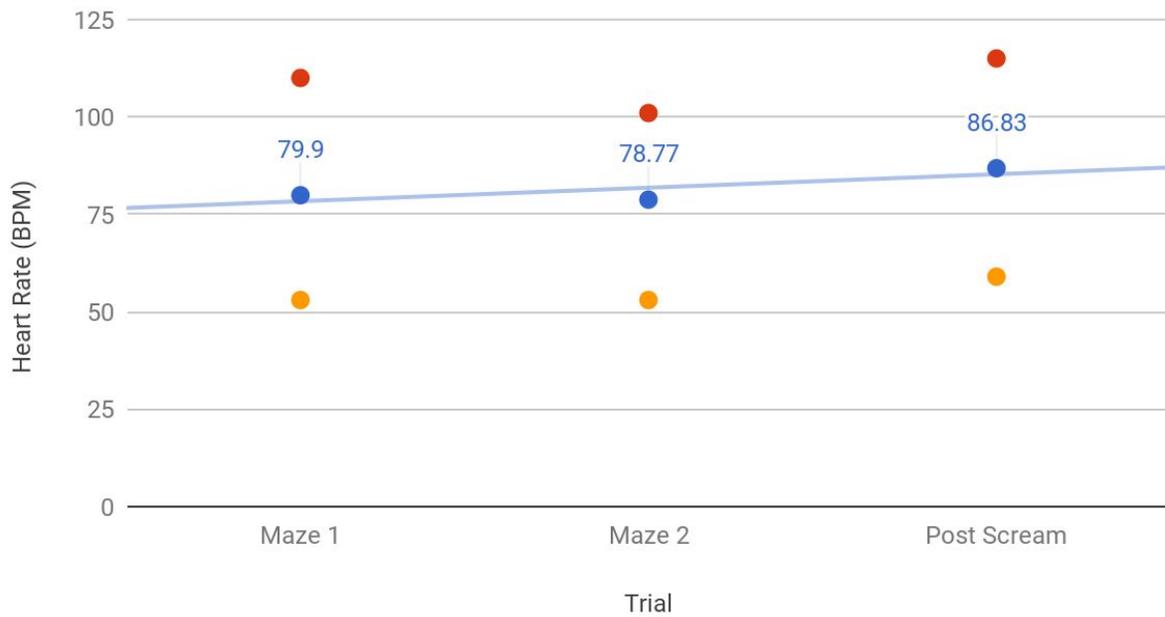


Figure 5a. Average heart rate was shown to increase from trials 1 and 2 to trial 3, providing evidence of a sympathetic response. Blue values indicate the averages across all participants. Red values are maximum and orange values are minimum values for each trial.

Average Respiration Rate by Trial

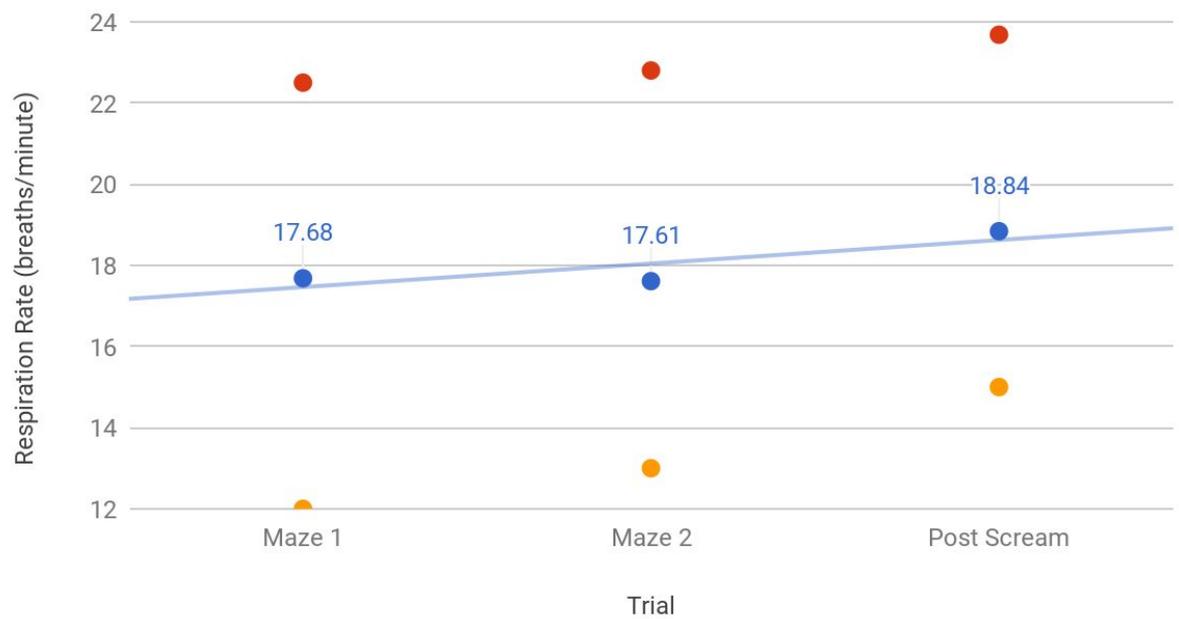


Figure 5b. Average respiration rate was shown to increase from trials 1 and 2 to trial 3, providing evidence of a sympathetic response. Blue values indicate the averages across all participants. Red values are maximum and orange values are minimum values for each trial.

Average Reflex Response Time

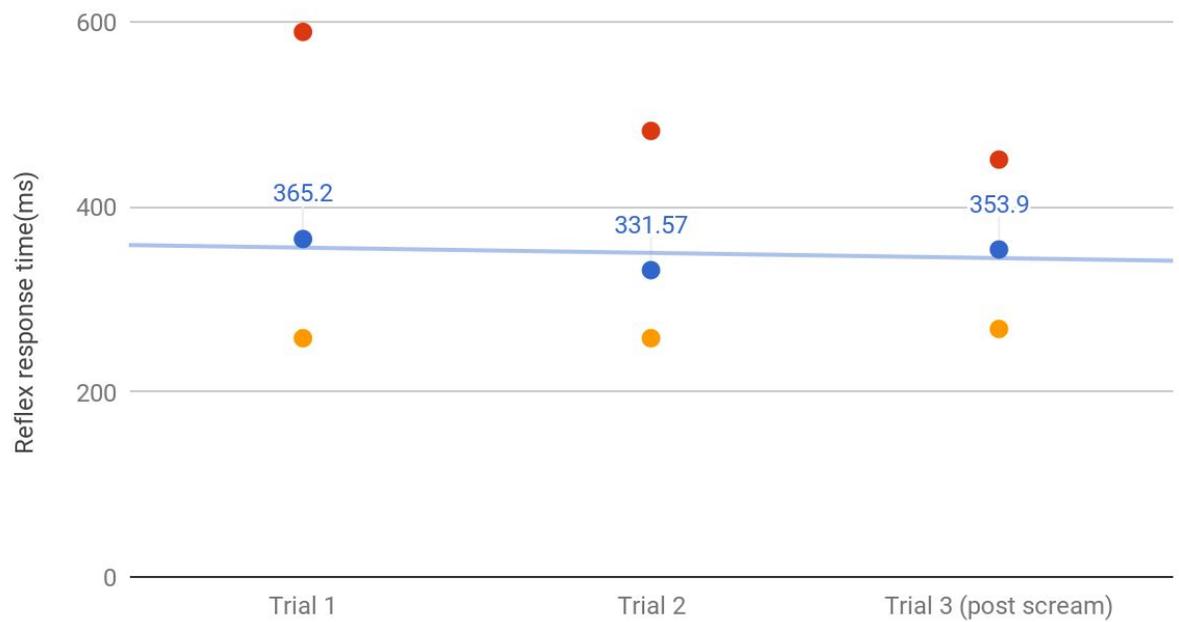


Figure 5c. Average reflex response time did not significantly change across 3 trials. The sympathetic response did not elicit a faster response time. Blue values indicate the averages across all participants. Red values are maximum and orange values are minimum values for each trial.

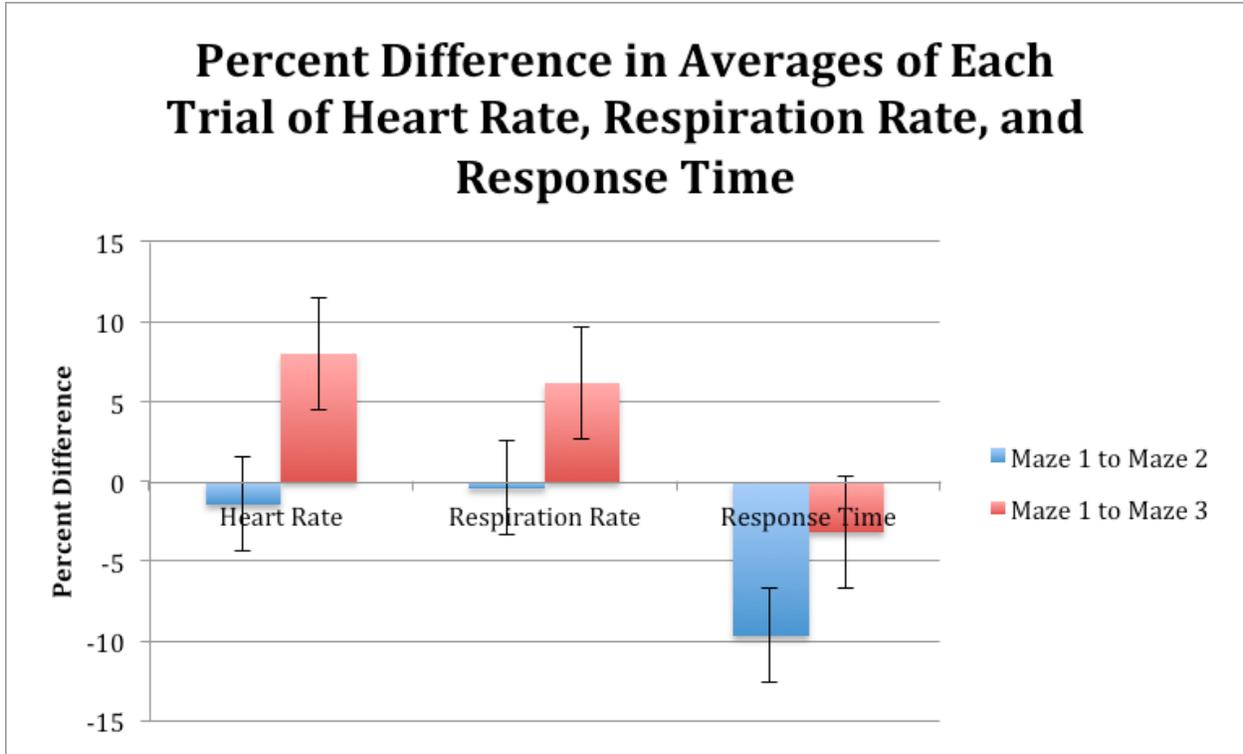


Figure 6. Positive values from baseline represent an increase in either heart rate, respiratory rate, or response time while negative values represent a decrease. The error bars represent the standard error.