Effect of Cold Pressor Test on Reaction Time

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Abstract

The purpose of this study was to examine variation in reaction time when a Cold Pressor Test (CPT) was administered. The three minute CPT was conducted in attempt to increase a person's sympathetic response. Heart rate and blood pressure measurements were recorded throughout the test to accurately monitor participant's response. In the study, the CPT was paired with an audio reaction time test conducted during the first and third minute of the experiment. The recorded measurements were then compared to the subjects' baseline heart rate, blood pressure, and reaction time to determine statistical significance. It was found that average initial heart rate increased ($n=37$, $p=6.14E\text{-}7<0.05$), however the average mean arterial blood pressure (MABP) showed no significant change, thus leading to inconclusiveness in the degree of sympathetic activation due to the CPT. Compared to the average reaction time in room temperature water, the average reaction time during the cold pressor test decreased ($n=37$, $p=0.0307<0.05$), suggesting that the CPT had an effect on the reaction time of the individual. Further studies that also increase the sympathetic response could be conducted in order to allow for a better comparison between sympathetic response and reaction time.

Introduction

Extremely cold conditions have been found to activate a physiological stress response in the body in order to maintain homeostasis (Lambert et al., 2014; Lambert and Schlaich, 2004; Victor et al., 1987). These cold conditions, typically seen during the winter in Wisconsin, can be partially replicated in the laboratory using the Cold Pressor Test (CPT). The test consists of immersing a subject's hand in ice water for a specified period of time and recording various physiological responses. Previous studies have found this test can increase global sympathetic activation in the body in response to the cold stress (Victor et al., 1987). In general, the sympathetic nervous system is functionally related with the psychological concept of arousal (Dawson, et al., 2000) and is responsible for mobilizing the organism's resources to meet the internal demands and those of the external environment (Salvia et al., 2012).

Due to the increased response of the autonomic nervous system, it is believed that the extremely cold conditions of the CPT will affect a person's reaction time, conceptualized as the delay between the stimulus presentation and the beginning of the response. Studies examining the effects of the CPT have found that an immediate response in muscle sympathetic nervous activity (MSNA) is seen in the first 30 seconds of the test. In one study, MSNA was recorded using microneurography in a muscle fascicle of the peroneal nerve at the fibular head. It was found that after approximately two minutes the neural response decreased and reached a stable plateau (Lambert et al., 2014). Another study conducted by Victor et al., (1987) found that the immersion of the hand for one minute in water at approximately 2°C created a significant change in MSNA. Although there was variation in individual responses, an increase was seen in all participants.

Previous studies have also measured additional physiological factors affected by the stress induced by the Cold Pressor Test. Lambert et al., (2014) found that there was an increase in mean blood pressure (BP) and heart rate (HR) during the first 30 seconds of the test, with the

HR decreasing and BP reaching a stable plateau after two minutes. The study suggested that the decrease in HR and plateau of BP was due to the body's homeostatic response.

Research conducted looking at the possible physiological determinants of these results have found that when the body is presented with a physically stressful situation such as being exposed to extreme cold, a surge of catecholamine hormones is released. Specific hormones identified include epinephrine, norepinephrine, and the main stress hormone of the body, cortisol. Cortisol is released from the zona fasciculata in the adrenal medulla and is permissive of adrenergic receptors which helps maintain blood pressure by supporting the sympathetic response system (Randall, 2011). The other catecholamines, norepinephrine and epinephrine, will then target the presented adrenergic receptors, causing an increase in heart rate and vasoconstriction, thus increasing blood pressure ("Stress and High Blood Pressure," 2006). In order to maintain constant body temperature, the body will also decrease the blood flow to the hand to reduce heat lost to the cold. The increase in sympathetic nervous activity will increase blood pressure and heart rate, which will lead to an increase in cardiac output, hence a higher capillary filtration rate in vascular beds within muscle tissue. This will increase the availability of oxygen and nutrients, particularly calcium, which will allow for increased muscle contraction.

Utilization of the Cold Pressor test will allow the stimulation of a stressful situation in an ethical manner to induce a physiological response. Heart rate and blood pressure will be measured in attempt to determine the level of stress response within the body. Reaction time will be measured at the same time in order to observe the effect of this stress response. If heart rate and blood pressure change under the experimental conditions relative to the control measurements, it will ensure that the participant is undergoing a physiological stress response. Observing an increase in both heart rate and blood pressure under this stressful condition will specifically indicate an increase in sympathetic response. Under normal conditions, vasoconstriction of blood vessels within the arm is directly caused by cold conditions. The increase of mean arterial blood pressure, calculated using the following equation: $[(2 \times \text{diastolic}) + \text{systolic}] / 3$, will then cause a decrease in heart rate. However, if the sympathetic response is activated due to the stress response caused by the cold temperature of the water, a release of catecholamines from the adrenal medulla and from the peripheral nervous system will be seen. Thus, instead of observing a decrease in heart rate, an increase is expected in both heart rate and blood pressure ("Understanding the Stress Response" 2011). A statistically significant change in these measured physiological factors could then explain a change in reaction time.

Determining how a person's reaction time is affected after the cold pressor test potentially suggests how quickly a person may respond to a stressful situation in general, or specifically during cold-induced stress. We speculate increasing a sympathetic response in the body will increase a person's reaction time.Variation in participants' heart rate and blood pressure will also provide information on the body's physiological response to one type of stressful situation and allow hypotheses on the effects felt by people continually exposed to these type of situations.

Materials and Methods

Subjects

Our study tested 37 undergraduate students enrolled in Physiology 435 who voluntarily participated. The participants were informed of the organization and details of the study before signing the consent form and were aware that they could withdraw themselves at any point during the study. Due to the constraints of the materials provided as well as the design of our study, only participants who classified their right hand as their dominant hand were used for the study.

Materials

The cold pressor mechanism, which was used to administer a sympathetic response, consisted of a container filled with ice water set to 2-4°C, monitored by a mercury-in-glass thermometer. A similar container of water set to 22-25°C, monitored by a mercury-in-glass thermometer, was utilized to record baseline measurements. In order to verify that an increase in sympathetic response was carried out, heart rate and blood pressure were measured when the participant underwent both the room temperature water bath and the Cold Pressor Test (CPT). Heart rate was measured via a Nonin Pulse Oximeter/Carbon Dioxide Detector monitor Model #9843, which was attached to the participant's right index finger during the entirety of the experiment. Mean arterial blood pressure was measured using the electronic Microlife Deluxe BP Monitor Model #BP3NQ1-42 which strapped onto the participant's left arm. To consistently make these measurements at the appropriate times, a standard timer was used. To test the participant's reaction time in the room temperature water bath and CPT, a BIOPAC® (Copyright-Goleta, CA) auditory reaction time test was administered. This consisted of a set of headphones that the participant wore and a clicker device that the participant pressed down with their thumb once an audio signal was produced. The reaction time was measured by the time it took the participant to press down the buzzer once he or she heard the audio signal through the headphones, and was recorded into the BIOPAC® program connected to a computer.

Study Design

To eliminate as many confounding variables with our experiment as possible, each participant was his or her own control, meaning that physiological measurements of heart rate, blood pressure (systolic and diastolic), and reaction time were recorded prior to and during the cold pressor test, so that a statistical comparison could be analyzed, see Figures 2,3, and 4. Prior to the cold pressor test, each participant was asked to put his or her left arm in container filled with water at a temperature between 22-25°C so that every participant started with the same baseline hand temperature.

Experimental Procedure

After explaining the study to the participant and addressing any questions or concerns, the participant was seated into a chair in a quiet room and hooked up to the equipment noted above. The blood pressure cuff was strapped in the correct position on the participant's left arm, the Pulse Oximeter was placed on the participant's right index finger, headphones fully covering the ears of the participant, and a clicker was placed in the participant's dominant (right) hand hooked up to the BIOPAC® system to measure the participant's auditory reaction time.

Participants were asked to close their eyes, sit quietly, and place their left hand into a plastic container filled with water at room temperature to a point just above the wrist. Upon submersion of the participant's left hand, the electronic Microlife Deluxe BP Monitor Model #BP3NQ1-42 and BIOPAC auditory reaction time test were started. Correspondingly, heart rate was measured and documented for the first time using the pulse ox.

The first blood pressure recording was started as soon as the subject placed their hand in the water and gave a reading approximately 45 seconds into the experiment. Following the minute long auditory reaction time test, the mean reaction time for each participant was obtained using the BIOPAC® system.

The auditory reaction time test consisted of ten auditory stimuli, static beeps administered directly to the participant through the headphones provided, in random intervals over the course of the minute. The participant responded by pushing the clicker with the thumb of his or her dominant hand, with minimal movement of the rest of his or her arm. Additionally at this time, heart rate was again measured and documented.

The participant, still with his or her left hand in the bucket of room temperature water and eyes shut, sat silently for one minute without any tests transpiring. At the conclusion of this minute, heart rate was measured again and the reaction time test was again given in dissimilar random intervals over the course of a minute. Fifteen seconds after the reaction time test had begun, the electronic Microlife Deluxe BP Monitor was activated. Approximately forty-five seconds after the blood pressure machine had started, the participant's blood pressure was noted. At the end of the minute long reaction time test, the mean reaction time for each participant was again documented. Heart rate was measured and logged for a final time. The participant's hand was then removed from the room temperature water, dried with paper towels, and was allowed to relax for three minutes before beginning the cold pressor test.

The participant subsequently placed the same hand that was immersed in the room temperature bucket of water into the 2-4°C bucket of water and the exact process from above was repeated. For a condensed outline of the procedure, see Figure 1. If the participant was unable to keep his or her hand in for the duration of the experiment, the results were not included in our statistical analysis.

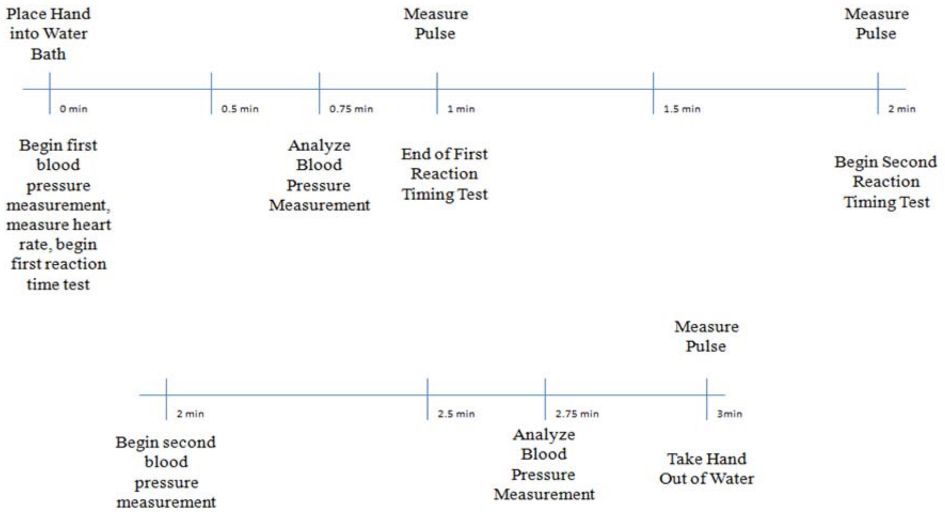

Figure 1. Summary of procedure for the three minute duration of the experiment in the room temperature water bath. The same procedure was then completed for the cold water bath with a three minute break in between tests.

Provided below are three participants as positive controls for our experiment. These show an increase in heart rate, blood pressure and decrease in reaction time to show that there is a change in these values.

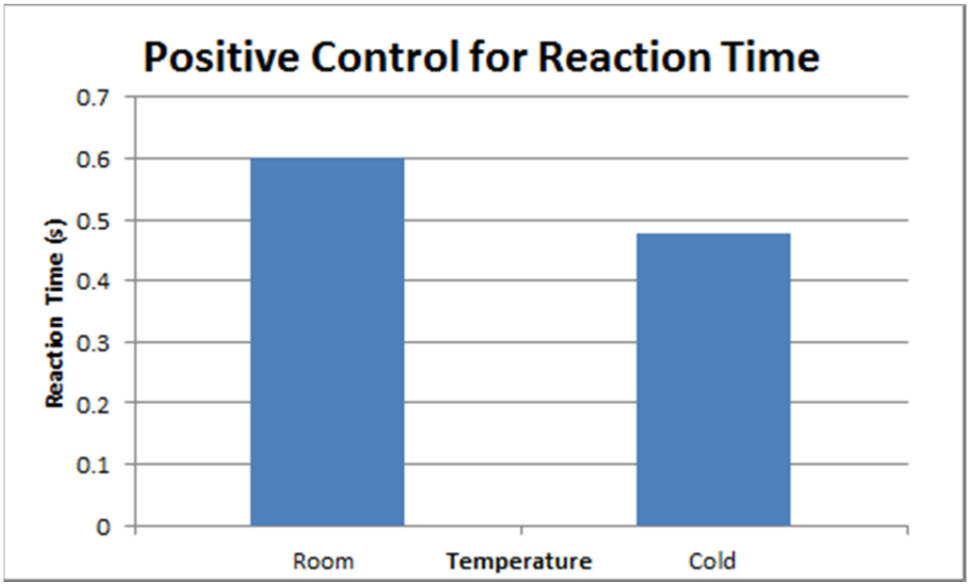

Figure 2. The positive control for reaction time showed a significant decrease in reaction time from the room temperature water to the cold temperature water.

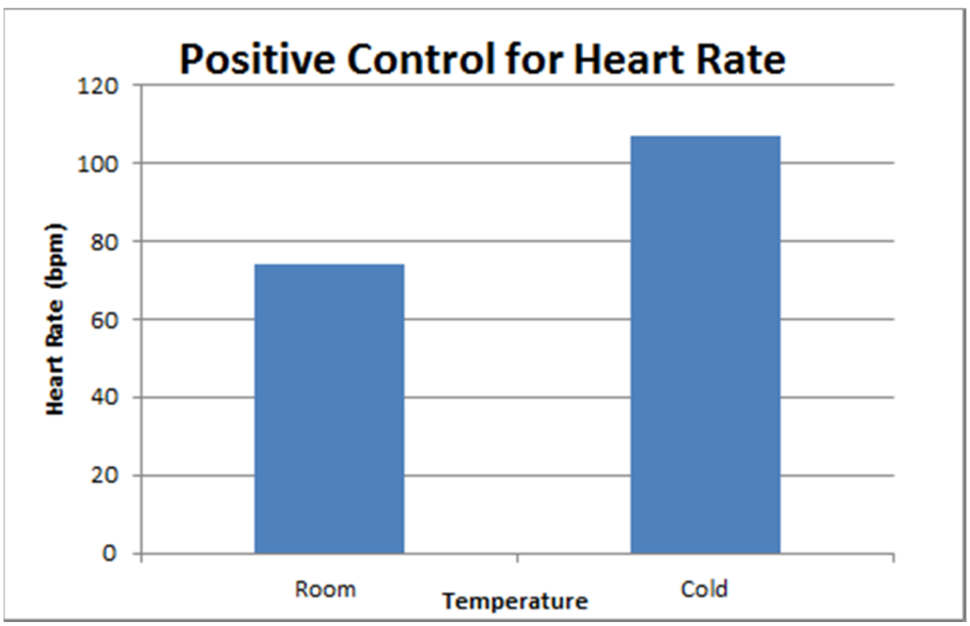

Figure 3. The positive control showed an increase in heart rate while going from being exposed to the room temperature water to the cold temperature water.

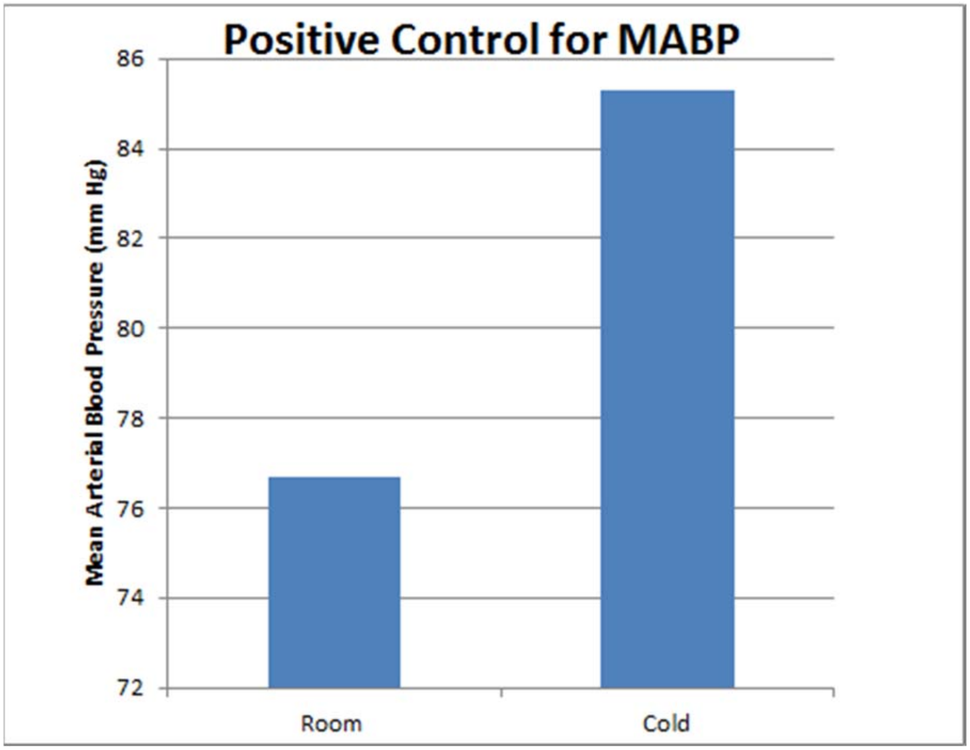

Figure 4. The positive control for MABP showed an increased difference between the room temperature water and cold temperature water.

Results

Average reaction time was calculated for room temperature water at 0.319 seconds and during the cold pressor test at 0.303 seconds. A paired t-test with a 95% confidence interval was conducted to determine the effect of the cold pressor test on participants' reaction time and a p-value of 0.0307. It was found that reaction time significantly decreased, see Figure 5.

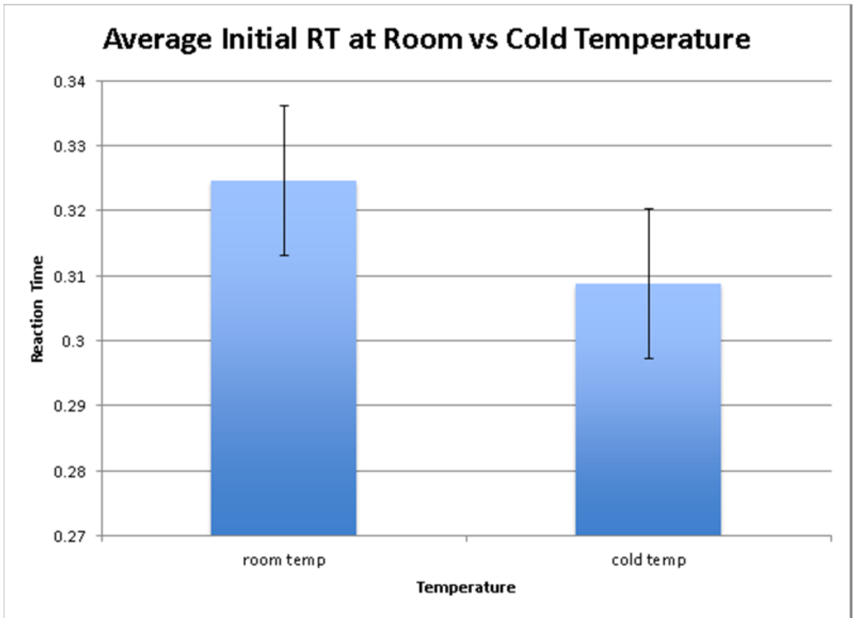

Figure 5. Thirty-seven subjects were tested first using room temperature water and then tested using cold temperature water. Their reaction time was measured throughout different time points within the test using an auditory stimulus.

Average initial heart rate at room temperature water was 76.1 beats per minute and during the cold pressor test was 84.8 beats per minute. From performing a paired T-test with a 95% confidence interval, a significant increase in heart rate was found between the room temperature and cold pressor test. The p-value of the data was 6.14E-7. A comparison of participants' heart rate variation can be seen in Figure 6.

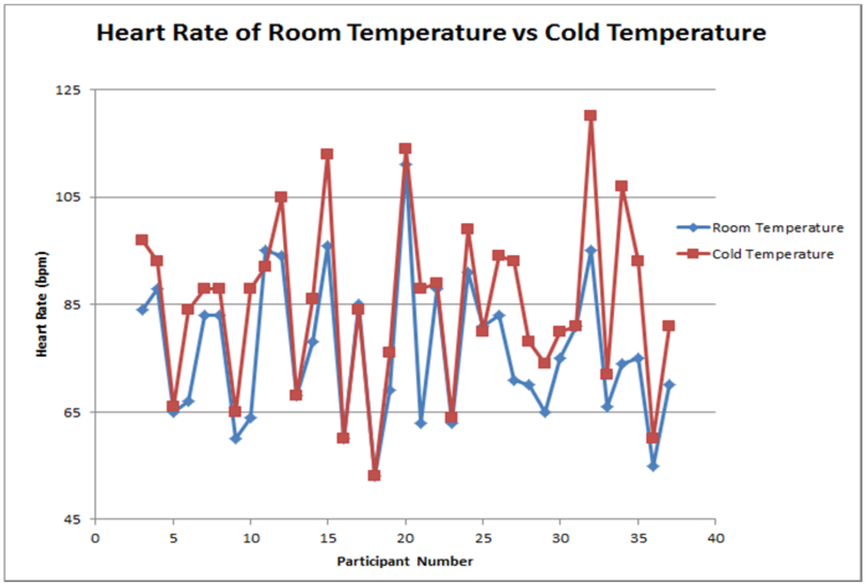

Figure 6. Heart rate measurements of thirty-seven participants while undergoing experiment in room temperature bath and then again during the CPT.

The average initial mean arterial blood pressure at room temperature water to be 90.38 mm Hg, while the average initial point mean arterial blood pressure during the cold pressor test was 86.4 mm Hg, see Figure 7. A T-test was performed and there was no significant change in MABP observed between the room temperature and cold pressor test. The test was performed with a 95% confidence interval and a p-value of 0.113 was found.

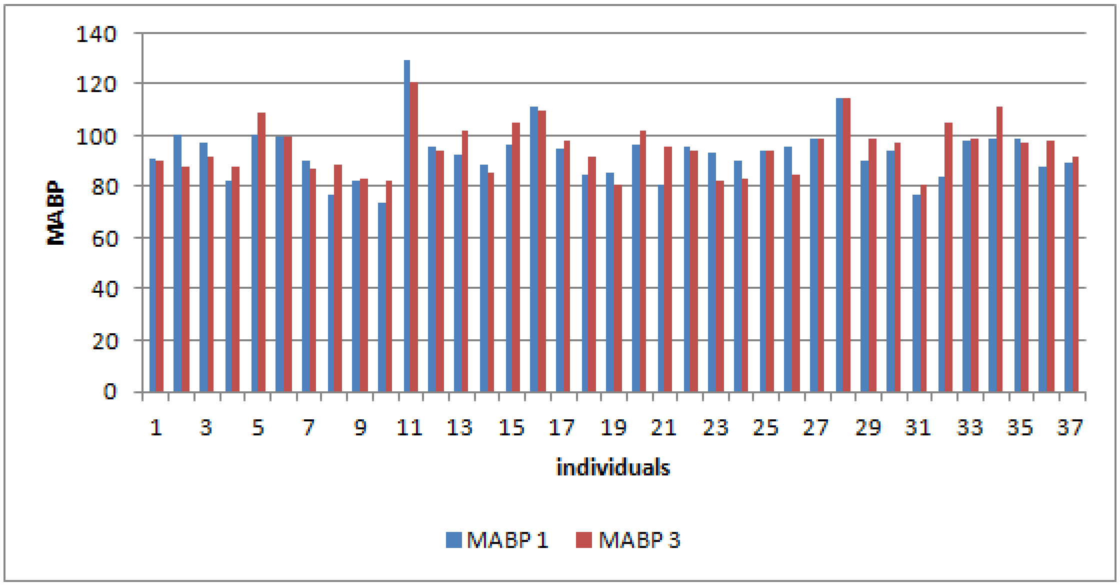

Figure 7. MABP measured at the initial time point (10 seconds after submersion of participant's hand) of the test showed a mean of 90.38 mm Hg during the room temperature test and 86.40 mm Hg during the cold temperature test. There was no significant increase in blood pressure found.

The average second point mean arterial blood pressure for room temperature water was 93.21 mm Hg, while the average second point mean arterial blood pressure during the cold pressor test was 95.21 mm Hg, see Figure 8. A T-test was performed and there was no significant change in MABP observed between the room temperature and cold pressor test. The test was performed with a 95% confidence interval and a p-value of 0.056 was found.

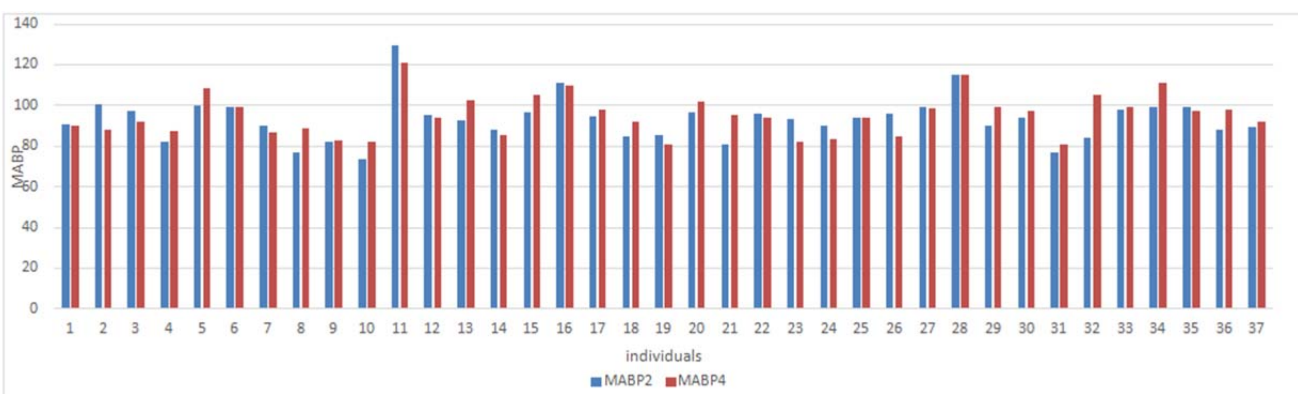

Figure 8. MABP measured at the second point (2 minutes after submersion of participant's hand) of the test showed a mean of 93.21 mm Hg during the room temperature test and 95.21 mm Hg during the cold temperature test. There was no significant increase in blood pressure found.

Discussion

The observed changes in the participant's physiological measurements of heart rate, blood pressure, and reaction time when compared to the room temperature water bath proved that the Cold Pressor Test successfully influenced a physiologic response in the body. Consistent with our hypothesis, the data showed a statistically significant decrease (p-value < 0.05) in auditory reaction time upon submerging one's hand in the ice water bath compared to the room temperature water bath. A statistically significant increase was also observed in subject's heart rate when going from the room temperature water bath to the ice water bath. This change was consistent with previous studies' results (Mourot et al., 2009).

It was found that blood pressure did not show a statistically significant difference when participants submerged their hand in the ice water compared to the room temperature water. However, a statistically significant decrease was found upon initial submersion of the participant's hand in the room temperature water. A potential explanation of this result could be attributed to previous participants informing future participants about the methodology of the study. Knowledge of the cold water bath could have been a cause of anxiety during the control bath due to the initial belief it was going to be the cold water bath. This may have led to higher resting MABP in the room temperature water bath compared to subject's true resting MABP. It was seen that the cold water bath slightly increased the MABP above the resting MABP. This could be due to the delayed sympathetic effect of epinephrine, as it is a neurohormone traveling through the bloodstream. Epinephrine ultimately causes an increase in the stroke volume of the heart by targeting Beta1-adrenergic receptors on the ventricle walls, leading to an increase in MABP. Limitations in recording blood pressure measurements included an inability to receive a reading upon immediate submersion of the participant's hand. This was due to the automatic blood pressure machine needing a 30-40 second delay from its start-up to give an accurate reading. This prevented an observation of the potential increase in sympathetic response immediately upon putting one's hand in the cold water bath.

Although statistically significant results were obtained from the study, limitations in methodology were noted. Conducting the reaction time test during the entire duration of the experiment without a one-minute break in-between each reaction time test would have been more complete. These modifications would yield more data points and help establish a higher level of significance in a bigger population. Also, the technology of our materials could have affected our results, specifically the tank used to administer the CPT. A more advanced tank consisting of pumps to create a continuous circulation of water would allow water temperature to remain at a constant temperature. This technology would also prevent the development of a microenvironment of warm water from forming around the subject's hand which would allow for constant conditions throughout the experiment.

Limitations in the reaction time test were also seen. Reaction times were found to improve with more exposure to auditory stimuli which could have been attributed to a learning factor. Although the signals were randomized over different intervals, the participant could have been primed and ready for what was coming, producing faster reaction times than expected. Additionally, while the experiment was conducted in an enclosed room, conditions could have been distracting from outside stimuli which ultimately could have distracted the participants who were listening for the auditory stimuli. Privacy of our study was also of concern which may have been a possible confounding factor. As previously mentioned, it was observed that participants who completed the experiment would discuss with their peers about our research study, making new participants nervous and anxious before the study. This was evidenced by the comments participants would say after the room temperature test was completed and by the higher resting heart rates and blood pressures as compared to their heart rate and blood pressure once they figured out they were not putting their hand in a cold water bath to begin with. This feed forward response was seen more towards the end of the testing periods, indicating that participants would warn others about the experiment. For example, participants would comment that it was not as bad as they had anticipated. In reality, they had not completed the "hard" part of the experiment yet; the ice water bath. When informed that the cold water bucket would be next, a feed-forward response was seen again and their heart rate increased dramatically even before submerging their hand in the water.

Although the cold pressor test is known to play a role in increasing one's sympathetic response, this increase could be contributed to other factors that were not examined in our study such as the brain and central nervous system. Critchley et al., (2000) described how brain activation can also elicit an arousal in the autonomic nervous system. The increase mental activity needed for the reaction time test could have been a factor contributing to the increase in sympathetic activity seen in the increase of participant's heart rate. Use of an electroencephalography in the future would allow the measurement of brain activity to determine if the increase is statistically significant.

Overall, increasing a sympathetic response was seen to be ineffective as skewed MABP results were seen. Almost every subject displayed a significant increase in his or her heart rate when in the cold water bath compared to the room temperature water bath, however, the blood pressure data was not statistically significant. Having each participant be his or her own control proved to be very beneficial. We were able to see how each individual reacted in the two water baths, and then compare the potential sympathetic response of the population as a whole.

If future studies were to be done extending off this research, the recording of MABP should be more efficient. Determining a near-instantaneous blood pressure change right after a hand placement in water was something our study was not capable of completing. There is a lot of valuable information that could be recorded right at the onset of the CPT that our study did not record; this information could help explain the sympathetic nervous system effect on reaction time. Furthermore, other studies could record the same measurements using different methods to increase sympathetic response or measure other variables besides heart rate and blood pressure while measuring reaction time. The cold pressor test is an ethical and efficient way to affect the sympathetic response, but there are many different ways of activating the sympathetic system, as demonstrated by Fechir et al., 2008. Principal investigators of this study discovered that each of these mental stressors would induce a certain level of sympathetic activation. There are also many variations that can stem from the study we completed such as examining the correlation between the amount sympathetic nervous system induction and reaction time of individual. Thus, we believe there is a great amount of research to be done to understand the connection between the sympathetic nervous system and reaction time.

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Tables/Figures

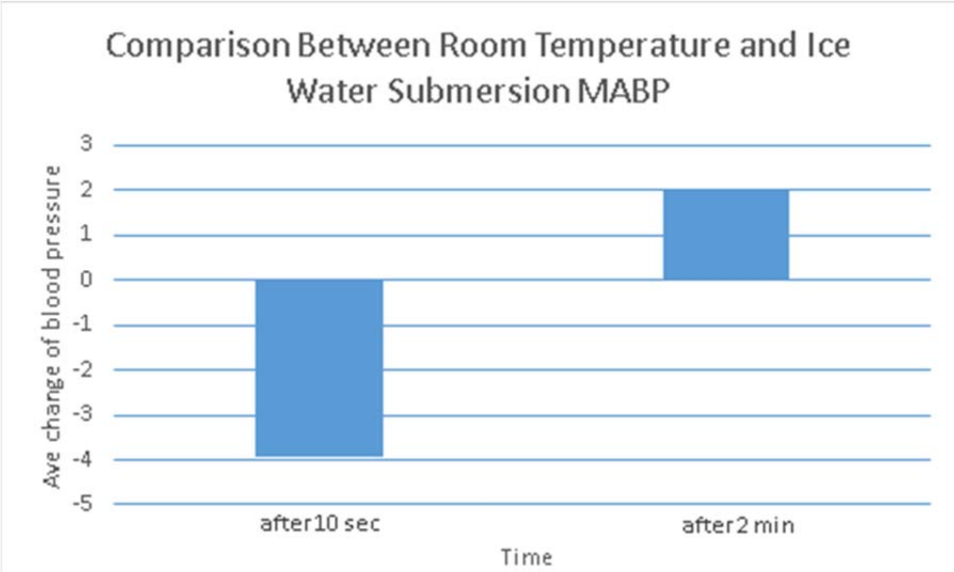

Figure 9. The average change in MABP measured at given time points in the room temperature water bath and the ice water bath. There was decrease in the initial values of MABP measured at 10 seconds, while there was an increase of MABP measure at 2 minutes into the protocol.

Temperature	Time	MABP average	RT average
Room	Initial	90.38	0.3194
	3 min	93.21	0.3031
Cold	Initial	86.43	0.3025
	3 min	95.21	0.2778

Table 1: The average blood pressure and reaction time for 37 subjects was recorded. Blood pressure and reaction time were measured simultaneously twice after subjects submerged their dominant hand in each water bath.