Effects of a Cold Environment on Motor Function and Homeostasis

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# Abstract

    Construction and medical rescue workers are often exposed to severely cold temperatures in winter while performing daily tasks for work. When the body is exposed to cold temperatures, a change in the body’s homeostasis and motor function occurs to adapt to the environment. Such physiological changes include a change in blood pressure, heart rate, grip strength, and reaction time to an external stimulus due to a distraction by the cold temperature. These changes can endanger the workers as they are more prone to work-related accidents when these physiological changes occur. In medical rescue workers, this also puts their patients in danger, as the workers may be more accident prone under these conditions. To further understand the extent of the physiological change, a hand dynamometer was used to test grip strength while blood pressure was measured by a sphygmomanometer. Other physiological parameters measured included heart rate through the use of a pulse transducer, and reaction time through the use of a push button switch. These parameters were measured before and after a minute long exposure to a cold water bucket or room temperature water bucket. The results did not coincide with the physiological changes expected to occur within the body when exposed to a cold stimulus; this may be due to the cold stimulus being given to a localized area rather than a whole-body exposure. Understanding physiological tendencies after exposure to a cold stimulus can further be applied to recognizing safety hazards for workers in a cold environment.

# Introduction

    Cold weather emergencies can lead to a variety of different health and safety challenges. Cold weather is known to elicit physiological changes within the body. This can be further understood by observing the differences in motor function and homeostasis within the body when it is exposed to frigid temperatures. This research allows for one to better understand the physiological effects of such temperatures on the body. It was expected that after the body is exposed to a cold environment, the motor function will decrease, and homeostatic tendencies will increase in an attempt to return the body to homeostasis.

    During exposures to cold temperature, heat is transferred from the body to the environment. This is explained through the Second Law of Thermodynamics, which states that entropy in the environment, the measurable amount of unusable energy, is always increasing (E.D.Schneider, 2002). Heat is taken up by the surrounding colder environment in an attempt to balance the temperatures of the environment and the body. The body, however, has two compartments that regulate heat transfer. The inside core contains heat producing organs to keep heat in and the body’s outside shell made of skin and subcutaneous fat. This permits heat transfer in and out of the body regardless of the environment (Kuht & Farmery, 2018). Cold temperatures cause the body to lose heat, since we are endothermic in nature.

    When exposed to a cold environment, the hypothalamus detects the change causing peripheral blood vessels to constrict to reduce blood flow to these areas. This preserves the core body temperature. The hypothalamus may also stimulate the skeletal muscles to begin contracting rapidly, known as shivering, to increase the metabolism and production of heat within the body (Andrew J. Young, 1996). In an attempt to maintain homeostasis, a decrease in peripheral blood flow reduces convective heat that is transferred to the environment. This can be accomplished by vasoconstriction of peripheral blood vessels. This, coupled with short term exposures to cold temperatures can have an effect on systolic and diastolic blood pressure, pulse pressure, and mean arterial pressure (Xu *et al.*, 2019). The vasoconstriction of these blood vessels forces the heart to work harder to provide adequate blood flow, causing an increased heart rate. Vasodilation can reduce the core body temperature caused by exposure to cold environments. When the body’s temperature falls below optimum temperature for proper functioning, dangerous and potentially fatal side effects can occur. Elderly, young children, and alcoholics are more likely to develop hypothermia than healthy individuals due to vasodilation. However, if the body is exposed to these cold temperatures for a long duration, shivering will stop and the exhausted body can go into organ failure. The information regarding the changes in blood pressure due to the cold can be further applied to increase awareness among those that are more susceptible to these dangers. These blood pressure changes have little effect on healthy people, however, it can severely affect people with cardiovascular disease.

    During strenuous exercises in cold environments, one is likely to experience greater muscle fatigue. This is due to the increased recruitment of muscle fibers to maintain muscle output in these colder temperatures (Oksa *et al.*, 2002). In these environments, muscle fatigue occurs at a faster rate in activities with repetitive activities. This is especially important when considering workers that are constantly exposed to cold temperatures, such as construction workers and medical rescue workers. Extended exposures to cold temperatures can impair tactile sensitivity, muscle function, grip strength, and proprioception (Ray *et al.*, 2019). In addition to impaired tactile sensitivity, individuals are also likely to experience an increased time to react to stimuli when exposed to the cold. This may be caused by neuronal distractions from the cold environment, making it more difficult for them to focus on other stimuli (Teichner, 1958). To enhance the retention of learned occupational and survival skills, individuals should be prepared and trained to adapt to the cold. However, cold temperatures are used today when attempting to relieve muscle fatigue, such as athletes taking ice-water baths after a strenuous workout to aid in the recovery process (Chow *et al.*, 2018). This information may also be used to better understand the dangers of freezing temperatures on our bodies.

    Based on current research on physiological responses due to cold temperatures, we hypothesized that if the body is exposed to a cold environment then the motor function will decrease and homeostatic tendencies will increase in an attempt to return the body to homeostasis. In this study, our experiment was set up to determine how the exposure to cold temperatures affected physiological changes within the body. Each subject’s dominant arm was submerged to their elbow in either room temperature water or ice water for one minute. Ice water was used to simulate the effects of cold temperature in a laboratory setting. It was expected that there will be no significant changes before and after exposure to room temperature water, while exposure to ice water will elicit a significant increase in blood pressure, heart rate, reaction time, and decrease in grip strength. It is important to better understand the physiological changes that occur when the body is exposed to extremely cold temperatures to better protect workers that are constantly exposed to such conditions

# Methods

    Before initiating the experiment, the volunteer filled out a pre-experiment questionnaire. The questionnaire allowed for the subjects to share any history of high blood pressure, if they work in a cold environment, their average heart rate, and other related information. Each step of the procedure was explained to the volunteer, allowing them to ask any questions regarding the experiment. The selected population for this experiment consisted of male and female college students between the ages of 18 and 22 years old. The volunteers for the experiment provided a baseline value of the grip strength, heart rate, blood pressure, and reaction time. This baseline then allowed for direct comparisons to be made based on changes in these measurements after being exposed to the cold temperature. Six males and six females performed the experiment with ice water(5o C) while two females and two males performed the experiment with room temperature water (20oC).

## Materials:

Stimulating bar electrode with hand dynamometer to test grip fatigue

Pulse transducer to detect the change in pulse due to temperature

Sphygmomanometer with a stethoscope to detect the change in blood pressure due to cold temperature

Push button transducer to measure reflexes and reaction times

## Procedure 1: Baseline Blood Pressure and Reaction Time

    Set up the sphygmomanometer onto the subject’s non-dominant arm and use the stethoscope to manually determine the blood pressure of the subject. Remove the sphygmomanometer and set up the push button transducer for the volunteer’s dominant hand. Instruct the subject that the software has been preprogrammed to provide randomized auditor cues. The subject may use the first 5 auditory cues as practice once the recording has started. Have the subject push the transducer as soon as they hear the auditory stimulus. Record until the subject has accurately responded to 10 auditory cues. Remove the push button transducer from the subject’s dominant hand. Analyze their reaction time by averaging the difference between the time of stimulus and time of reaction.

## Procedure 2: Baseline Grip Strength and Heart Rate

    Have the subject sit in a relaxed position and strap the pulse transducer on the index finger of the non-dominant hand. Be sure that the palm is facing upwards and the pulse transducer is not resting on any surfaces. Calibrate the hand dynamometer to show the maximum grip strength in units of percent. Place the hand dynamometer onto the table and zero. Have the subject pick up the dynamometer in their dominant hand and calibrate with a medium then maximum force grip, and relax. Record pulse for the first minute of the exercise and then instruct the subject to grip the dynamometer with maximum force for 20 seconds followed by a 5-second rest. Repeat this task with the hand dynamometer three times. Take the average pulse for the first minute of the recording. Analyze grip strength through the percent achieved during grip 1, 2, and 3.

## Procedure 3: Grip Strength and Heart Rate after cold water submersion

    Tell the subject they will submerge their dominant hand up to their elbow in ice water or room temperature water for one minute. Before the arm is submerged place the pulse transducer on the index finger of the non-dominant hand. Have the subject submerge their dominant arm. At 50 seconds of hand submersion begin recording the pulse. When the total one minute submersion is complete, have the subject remove their hand from the ice water, quickly dry off the arm, and place the hand dynamometer into the palm of the subject. Instruct the volunteer to keep their non-dominant hand still through the transition. Have the subject repeat the steps for gripping the dynamometer in Procedure 1. Remove pulse transducer from non-dominant hand and remove the hand dynamometer from the dominant hand. Use the same analysis procedure from Procedure 1. Have the subject relax for 7 minutes to allow for the arm to warm up.

## Procedure 4: Blood Pressure and Reaction time after cold water submersion

    Place the sphygmomanometer on the subject’s non-dominant arm before submersion into water. Have the subject submerge their dominant hand into the cold water or warm water for one minute. After one minute have the subject remove their hand from the ice water, quickly dry off the arm, and set up the push button transducer into the dominant hand of the subject. Take the subject’s blood pressure immediately after drying off the arm when the subject is still. Have the subject repeat the steps for measuring reaction time in Procedure 2. Remove the sphygmomanometer and the push button from the subject and have them return to a relaxed position. Provide the same analysis as described in Procedure 2.

# Results

    Submerging the volunteer’s dominant arm into either room temperature water ice water was used to simulate the effects of cold water exposure on the bodies homeostasis and motor function. It was expected that there will be no significant changes before and after exposure to room temperature water while exposure to ice water for one minute will illicit a significant increase in blood pressure, decrease in heart rate, decrease in reaction time, and decrease in grip strength.

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## Effects on Blood Pressure

    It is hypothesized that the blood pressure will increase when the arm is exposed to the cold water due to vasoconstriction of the blood vessels, which causes an increase in resistance in the blood vessels, thus causing an increase in the blood pressure. During the experiment, the systolic blood pressure showed an increase (M= -2.67, SD= 12.60), while the diastolic blood pressure showed a slight decrease (M= 2.00, SD= 9.07) after exposure to the cold water. The systolic blood pressure showed a slight increase(M= -3.50, SD= 6.81) while the diastolic blood pressure showed a slight decrease(M=5.50, SD=5.26) after exposure to the room temperature water. The systolic blood pressure showed an increase (M= -2.67, SD= 12.60), while the diastolic blood pressure showed a slight decrease (M= 2.00, SD= 9.07) after exposure to the cold water. Figure 1 shows the change in systolic and diastolic blood pressure before and after the control and experimental stimulus was given. (hypothesis accepted or rejected?)

## Effects on Grip Strength

    It is hypothesized that the after exposure to cold water the average grip strength percent would be lower than before the stimulus. For the control group, it is expected that there is no change significant decrease in muscle fatigue when comparing before and after the stimulus. Figure 2 shows the average grip strength percent’s before and after the stimulus selected for the volunteer.  Through an ANOVA test, there was no statistical difference between the control and experimental values before and after each stimulus. Because there was no statistical difference the hypothesis was rejected.

## Effects on Heart Rate

   It is hypothesized that exposure to cold water will cause the heart rate to decrease. The control group is expected to have no significant difference before and after exposure to room temperature water. The average change in heart rate decreased slightly (M=2, SD=2.16) throughout the volunteers exposed to the room temperature water while the heart rate, on average, decreased (M= 4.92, SD= 10.34) after exposure to the cold water.

## Effects on Reaction Time

  It is hypothesized that exposure to cold water will decrease the reaction time. For the control group it is expected that there will be no change in reaction time after exposure to room temperature water. The average change in reaction times decreased slightly (M=0.04, SD=0.03) for the volunteers in the control group. The reaction times for the volunteers exposed to the cold water, on average, did not show a change (M= 0.00, SD= 0.03).

### Correlations Found with the Questionnaire

No significant correlations were found with the questionnaire.

# Discussion

## Important Findings

Understanding how exposure to a cold environment can decrease motor function can be applied to recognizing safety hazards for workers in a cold environment and to different conditions in a clinical setting. It was expected that throughout the control group there would be little to no variation within the tested parameters since they are not being exposed to cold water. There was a slight increase in the systolic blood pressure while the diastolic blood pressure decreased slightly. The heart rate, grip strength, and reaction time decreased on average. The slight decrease in average grip strength for the control could have been due to muscle fatigue. Because the grip strength was re-tested only three minutes between the baseline and post-exposure to the control stimulus, the muscles may have still been fatigued from the previous exercise.

    The data collected revealed that there was no significant difference between the reaction time of the subject before and after the cold stimulus. Based on the data the hypothesis that cold exposure would significantly decrease motor function was rejected. This could be because only the arm was subjected to the cold temperature, an isolated section of the body, instead of the whole body which would elicit a stronger response. The blood pressure would likely increase more due to a greater amount of vasoconstriction throughout the entire body, rather than a localized area of the body. The heart rate would also slow down more if the whole body were exposed to a cold environment to reduce the amount of peripheral blood flow, allowing for the central, core organs to receive adequate blood supply during the cold temperature. If the subject’s entire body was submerged in cold water, the results could have changed from the data collected in this experiment, allowing for more definite conclusions to be made.

## Limitations and Strengths

    This experiment had some limitations that lead to error in results and rejected the hypothesis. One limitation was how the subject only submerged elbow deep into ice water. The goal of this experiment was to find the effects of cold temperature on the body, however, what was actually tested was just a centralized area of the body. There was also a limitation to the accuracy of the equipment used. The equipment malfunction could have lead to some error in data results. The equipment at times would not work or would drift from baseline. The pulse transducer would often show the volunteer’s heart rate spiking to over 500 bpm.  The analysis could be more accurate with more participants, however, this experiment was limited in participants due to time constraints.

    This experiment had strengths that could be brought to further experiments. This experiment had a diverse group with equal amounts of men and women between 18-22 years old. This experiment also allowed for the simulation of cold exposure in a laboratory setting.

# Conclusion

    A better understanding of how cold exposures affect motor function and other bodily functions can be further applied to different clinical conditions and safety in the workplace. Although the experimental hypothesis was rejected based on the expected results differing from the actual results, further research can be performed learning from the limitations and strengths of this setup. For further research, testing the effects of cold exposure on the physiological responses in the body, one should consider a total body exposure to a cold environment. This would elicit a greater physiological response, rather than the minimal responses that this experiment produced with a localized region of the body being exposed.