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Cold stress and the cold pressor test

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Silverthorn DU, Michael J. Cold stress and the cold pressor test. *Adv Physiol Educ* 37: 93–96, 2013; doi:10.1152/advan.00002.2013.—Temperature and other environmental stressors are known to affect blood pressure and heart rate. In this activity, students perform the cold pressor test, demonstrating increased blood pressure during a 1- to 2-min immersion of one hand in ice water. The cold pressor test is used clinically to evaluate autonomic and left ventricular function. This activity is easily adapted to an inquiry format that asks students to go to the scientific literature to learn about the test and then design a protocol for carrying out the test in classmates. The data collected are ideal for teaching graphical presentation of data and statistical analysis.

inquiry; heart rate; blood pressure; autonomic function; temperature stress

TEMPERATURE AND OTHER ENVIRONMENTAL STRESSORS are known to affect blood pressure (BP) and heart rate (HR). In this activity, students perform the cold pressor test to demonstrate the changes in BP that follow an environmental stress. For cold stress, the subject immerses one hand into ice water for 1–2 min while group members monitor changes in the subject's BP from baseline to recovery.

Background

Temperature and other environmental stressors are known to affect HR and BP. For example, sudden and increasingly painful cold stress causes massive discharge of the sympathetic nervous system and release of norepinephrine. This sympathetic discharge triggers responses in the cardiovascular (CV) system that include arteriolar constriction, increased HR, and increased cardiac contractility. These responses combine to increase BP. This is known as the pressor response (21), and testing a subject with cold stress in this fashion is known as the cold pressor test. The cold pressor test has been used clinically as a stress test to assess left ventricular function (15). The test is also used to evaluate cardiac autonomic function (24) and as an experimental pain stimulus (23).

The test was once suggested as an index for screening subjects for hypertension (high BP) (8, 16). Several studies have indicated that the CV response to the cold pressor test can predict the future development of hypertension. Studies of black and white adults and children have indicated that black subjects, who are at increased risk for developing early hypertension, show stronger vascular reactions to the cold pressor test than do white subjects (10). The cold pressor test has been shown to dilate the coronary arteries of normal subjects but constrict the coronary arteries of hypertensive subjects (1). One study (14) used cold pressor test-induced coronary vasoconstriction to successfully predict subsequent adverse CV events (e.g., stroke or heart attack) in asymptomatic type 2 diabetic patients. Presumably the vasoconstriction is associated with endothelial dysfunction that results in long-term CV pathology.

Learning Objectives

After the completion of this activity, students should be able to do the following:

1. Describe and explain the physiological control pathways underlying the BP response to the cold pressor test

2. Develop a hypothesis and design an experiment to test it

3. Gather and analyze data and draw appropriate conclusions

4. Critique experimental design to improve future explorations

Activity Level

This activity would be useful in a variety of courses, including physiology, anatomy and physiology, general biology, human biology, honors biology, or Advanced Placement biology from high school through professional school.

Prerequisite Student Knowledge or Skills

Before doing this activity, students should have a basic understanding of the following:

1. Physiological factors that affect HR and BP

2. Autonomic nervous system pathways and responses

3. The types of sensory receptors in the body and where they are found

Students should know how to do the following:

1. Measure BP with a sphygmomanometer/BP cuff and stethoscope or with an automated data-acquisition system

2. Measure pulse rate, either manually or with a finger pulse transducer

Time Required

A simple demonstration of the reflex takes <1 h. If students are doing this as an inquiry activity, allow at least 1 h (in the laboratory or before the laboratory) for the background literature research, 30 min for planning and designing the experiment, and 1–2 h for data collection, depending on the number of subjects.

METHODS

Equipment and Supplies

Required equipment (1 set/group). The following equipment is required for this activity:

1. A sphygmomanometer/BP cuff or electronic equivalent

2. A stethoscope

3. A water bucket/pan

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4. Ice
5. A thermometer that can measure as low as 4°C
6. A clock or watch that can be read in seconds

Optional equipment (1 set/group). The following equipment is optional for this activity:

1. An ECG or HR monitor; alternately, a computer with physiological data-acquisition software (e.g., AD Instruments, Biopac, or iWorx) plus finger pulse transducer and sphygmomanometer transducer can be used
2. A refrigerated water bath
3. A stopwatch

Human Subjects Approval

This noninvasive experiment is considered an exempt educational activity by the Institutional Review Board of the University of Texas (Austin, TX). Adopters of this activity are responsible for obtaining permission for human subjects research from their home institution. For a summary of "Guiding Principles for Research Involving Animals and Human Beings," please see www.the-aps.org/mm/Publications/Ethical-Policies/Animal-and-Human-Research.

Instructions

1. Preparation: gather equipment. No additional preparation or followup time is required. A sample data collection sheet is shown in Table 1.

2. Prepare a pan of ice and water that can be maintained at 4°C. Note: you can use water in the 4–10°C range and expect to see a response.

3. Show students the ice water and ask them to write a hypothesis/hypotheses predicting the effect that immersing a hand in the water will have on the CV system. They should include a prediction of the impact of cold stress on BP, HR, and blood flow based on what they know about the autonomic control of BP and about thermoregulation. For example, one prediction might be as follows: "In the cold, cutaneous blood vessels constrict to limit heat loss across the body surface, and this vasoconstriction should increase BP."

4. Ask the subject to lie on his/her back (supine) or sit quietly for 5 min. It is preferrable to use the supine position, where feasible.

5. Take BP and HR two to three times to determine normal levels. Leave the deflated BP cuff on the arm.

Table 1. *Sample data sheet*

	Systolic Blood Pressure	Diastolic Blood Pressure	Heart Rate
Resting (normal) blood pressure and heart rate (before immersion)			
Trial 1			
Trial 2			
Trial 3			
Average			
Blood pressure and heart rate during immersion			
Elapsed time, min:s			
0:30			
1:00			
1:30			
2:00			
Blood pressure and heart rate during the recovery period			
Elapsed time, min:s			
0:30			
1:00			
1:30			
2:00			
2:30			
3:00			

6. Using the arm WITHOUT the cuff, immerse the subject's hand into the ice water, and leave it there for 2 min. If the cold becomes too painful, the subject may withdraw the hand at any time.

7. Determine BP and HR every 30 s for 2 min. Note: many of the clinical cold pressor tests use only 1 min of immersion. If subjects find that the hand becomes too painful for a 2-min test, shorten the test to 1 min. The experiment can also be done with the foot instead of the hand.

8. Remove the subject's hand from the ice water.

9. Immediately measure systolic and diastolic BPs and count the pulse rate at 30-s intervals until BP and pulse have returned to normal.

10. Calculate the average normal systolic and diastolic BPs from the data obtained before immersion. Subtract the average preimmersion pressures from the highest readings obtained during or after immersion.

- The change in BP provides an index of BP lability or reactivity.
- Subjects whose systolic BP increases by 25 or more mmHg or whose diastolic BP increases by 20 or more mmHg are considered to be hyperreactive (25).

Continuous Monitoring Method

Probably the most difficult technical aspect of this experiment is the necessity to take rapid serial measurements of BP. If students are using a computerized data-acquisition system with a sphygmomanometer transducer, it may be possible to monitor changes in BP with continuous readings, as described below.

1. The cuff of the sphygmomanometer must not leak. To test for this, inflate the cuff to a pressure below the subject's systolic BP and tighten the screw. Watch the trace on the computer screen to make sure that BP remains constant. Deflate the cuff.

2. Using measurements from your subject at rest, calculate mean BP as follows: mean BP = diastolic BP + 1/3 pulse pressure, where pulse pressure = systolic BP − diastolic BP.

3. When the experiment is ready to begin, put the cuff on the subject and inflate it to ~5 mmHg below the subject's mean BP. Hold the BP constant at this value by tightening the screw on the rubber bulb.

Start the recording. You should observe small pressure pulses on the trace as each pressure wave passes beneath the cuff. Increase the sensitivity of the *y*-axis if necessary. The trace on the recording will allow you to see changes in systolic BP as well as variations in the recording's baseline.

Safety Considerations

Individuals with ANY of the following conditions should NOT serve as a subject:

1. CV disorders
2. Neurological disorders
3. Smokers
4. Recently ingested caffeine

Students should be told emphatically that if the cold water becomes too painful, they should remove the hand immediately and not wait to the end of the test period.

Warn students about leaving the cuff inflated too long. If the subject complains of pain in the arm, deflate the cuff immediately.

Troubleshooting

Potential problems and solutions for this activity are shown in Table 2.

RESULTS

Expected Results

Arterial BP and HR should increase during hand immersion in cold water and then return to normal after the hand is removed (Fig. 1).

Table 2. *Troubleshooting*

Potential Problem	Potential Solution
Water temperature not in the correct range (4–10°C)	Measure the water temperature (ice).
Subject unable to keep hand in water	Screen subjects for ability to keep hand in water for 30 s.
Blood pressure measurement errors	Practice taking blood pressure quickly before starting experiment. If using a data-acquisition system, try the instructions for continuous monitoring of blood pressure. Make sure that the cuff is completely deflated between readings. Common mistakes include the following: •Not putting the cuff tight enough around the arm. •Not using the correct cuff size. Use smaller "child" cuffs for thin arms and "obese" cuffs for large arms. •Not placing the marking for the artery in the right place. •Not pumping up the cuff fast enough. •Keeping the cuff inflated at high pressure too long or taking too long to deflate. Never inflate the cuff above 200 mm Hg.
Hyporesponders versus hyperresponders skew data in small sample sizes	Provide quiet environmental conditions for the experiment. Pool data from multiple subjects and make a group data sheet (i.e., include as many data points as possible).

Evaluation of Student Work

Students should present their data as graphs. They can plot systolic and diastolic BP values and then calculate and plot mean BP. They may include HR data on a separate axis on the same piece of graph paper.

It is often useful to have students pool their data and do their graphs using compiled class data, as this gives them an opportunity to observe the variability inherent in a population of humans. If the class includes statistics, have students do both paired and unpaired Student's *t*-tests on the data to show how a paired *t*-test can show significance in a variable population that may or may not show significant before-after differences when analyzed with an unpaired *t*-test.

Questions for the Laboratory Report

Question 1. Which was greater: the effect of cold on systolic BP or on diastolic BP? What might account for this?

ANSWER. The literature predicts that the effect is greater on systolic BP. Sympathetic innervation will increase cardiac contractility, which influences systolic BP.

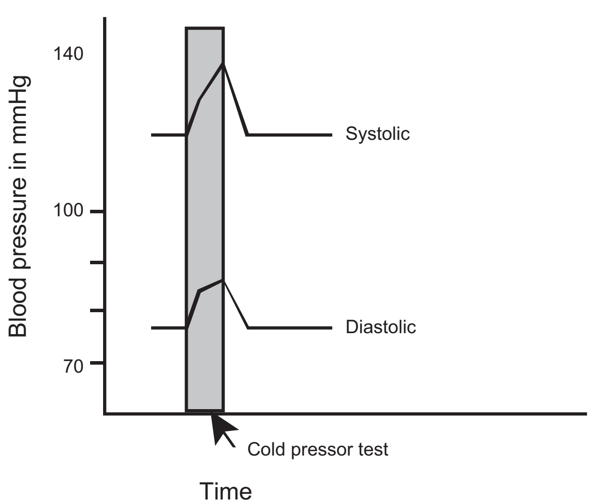

Fig. 1. Systolic and diastolic blood pressures before, during, and after the cold pressor test. [Data adapted from Ref. 16.]

Question 2. Are the changes in HR mediated by the autonomic nervous system? If so, which branch?

Question 3. Is the baroreceptor reflex functioning during the cold pressor test? Use evidence to support your answer.

ANSWER. No, the baroreceptor reflex is not functioning. If it was, the increase in BP would result in a reflex decrease in HR.

Question 4. What are the physiological mechanisms by which the cold pressor test works? Make a detailed map of the process beginning with the stimulus of hand into cold water and ending with increased BP.

Inquiry Applications

When the test is carried out as written in the instructions, this activity is a "cookbook" laboratory. To increase the inquiry level, the teacher can allow the students to decide what part of the body to expose to the cold (see note below), what temperature of water to use, and how long to expose the body part to cold. Students can also be asked how to control this test to rule out the possibility that it is the pressure of the water on skin that triggers the response (answer: repeat the test with body temperature or warmer water).

For an even higher level of inquiry, students are asked to learn about the cold pressor test on their own and to design an experiment to test for it. To do this, they must search the literature using PubMed (www.pubmed.com) and read published articles on the cold pressor test. The literature is explicit enough about the protocol that student-designed experiments should be very close to the protocol described above.

Students can use the cold pressor test to further explore aspects of environmental effects on BP and HR. Questions that students could ask and test include the following:

•What is the threshold temperature that triggers the cold pressor response?

•Does the threshold temperature vary from person to person?

•Does it vary by sex, racial/ethnic group, weight, age, etc.?

•Do different populations vary in the intensity of the response?

•Are there other stressors that affect BP that could be used for exploration?

Note: if cold is applied to the face, particularly in the nasal region, the stimulus may trigger a diving reflex, which is indicated by a decrease in HR (bradycardia) and little or no increase in BP. One inquiry experiment could be to have students determine whether the CV response to cold varies according to what part of the body is exposed to the cold stimulus.

Additional Resources

For additional information on this topic, please see Refs. 2–7, 9, 11–13, 17–20, 22, and 26.

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DISCLOSURES

No conflicts of interest, financial or otherwise, are declared by the author(s).

AUTHOR CONTRIBUTIONS

Author contributions: D.U.S. and J.M. conception and design of research; D.U.S. and J.M. performed experiments; D.U.S. and J.M. analyzed data; D.U.S. and J.M. interpreted results of experiments; D.U.S. prepared figures; D.U.S. and J.M. drafted manuscript; D.U.S. and J.M. edited and revised manuscript; D.U.S. and J.M. approved final version of manuscript.

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