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|  | **Hold Your Breath!**  *What triggers the dive response in mammals?* |

**Overview**

This module helps students learn about the mammalian dive response, a physiological response in mammals that optimizes respiration and blood flow to allow extended underwater dives. Students simulate a dive and induce the dive response by submerging their faces in cold water (~15oC) for 30 seconds. Students measure heart rate and peripheral skin temperature before and after the simulated dive, and identify bradycardia, or a reduction in heart rate, as an indicator of the dive response. They then develop hypotheses and experimentally test how additional factors might affect the triggering of the dive response, such as body position, water temperature, length of breath hold, or exercise. Students learn to separate controlled conditions from experimental conditions to test hypotheses effectively. This lab activity helps students understand how the human body responds to stress by diverting blood away from non-essential organs and skeletal muscle. Finally, students convey their findings by drawing appropriate bar graphs and may compose a formal lab report.

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| **Concepts**  Dive response, Apnea (Breath Holding), Bradycardia, Peripheral Vasoconstriction, Blood Flow, Skin Temperature, Human Stress Response  **Skills**  Heart Rate Measurement, Skin Temperature Measurement, Designing Experiments |  | **Module Type:** Lab Activity  **Duration:** 2 to 2.5 hours  **Key materials**   * Stopwatch * Infrared Thermal Sensor (~ $30) * Dishpan or tub with cold water (~15°C) * Thermometer for water baths (in Celsius) * Ice * Towels * Heart Rate Monitor (optional) (~ $40) |

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**Science Education Standards**

**National:** Science As Inquiry; Science and Technology; Life Science

**California:** Biology-Life Sciences: 9a Physiology; Investigation and Experimentation 1 a-d, f, j-l

**Field tested**   
Grades 11-12, Marine Biology, Watsonville High School, Watsonville, CA (Fall, 2012)  
Grades 11-12, Anatomy and Physiology, Watsonville High School, Watsonville, CA (Fall, 2012)

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# Background for Teachers

**What is the mammalian dive response?**

The mammalian dive response (also termed “mammalian dive reflex”) is a physiological response in mammals that allows them to extend the time they can dive under water by optimizing respiration and blood flow. It is exhibited most strongly in marine mammals such as seals, dolphins, and otters, but it also exists in other mammals, including humans.

The mammalian dive response includes three major physiological responses: (1) **apnea**, (2) **bradycardia**, and (3) **peripheral vasoconstriction**. **Apnea**, or breath hold, occurs naturally for any air-breathing animal that is submerged. **Bradycardia**, or reduced heart rate, leads to a reduced metabolism, which in turn helps conserve oxygen. The human heartbeat can slow by 10-25% when experiencing the dive response (Speck and Bruce, 1978). **Peripheral vasoconstriction** is another oxygen-conserving response. Blood is directed away from non-essential organs and from tissues such as skeletal muscle, which have their own oxygen stores in the form of myoglobin.

Overall, the dive response increases the availability of blood (and thus oxygen) to the brain and heart, but decreases oxygen consumption by the heart. The dive response is one of several adaptations that enable some marine mammals to remain submerged for over an hour.

**Why this matters:** This lab activity encourages an inquiry-based approach to understanding an interesting physiological adaptation that is found in mammals: the mammalian dive response. Students engage in critical thinking as they attempt to isolate the most pertinent factor(s) that trigger the dive response. They must design their own experiments in order to explore their curiosity effectively. This lab requires minimal set up and relies on few materials.

**Assumed background:** We assume students know how to compute averages (mean values) for a set of given numbers and know how to construct bar graphs to convey differences between categorical variables. We also assume that students already understand that oxygen delivery to tissues and organs is what makes respiration a vital process, and that tissues die without a supply of oxygen.

**Special context:** This lab is especially relevant to courses that include diving mammal physiology (such as a marine biology course) or human physiology.

**Scaffolding supplements:** A laboratory worksheet is included as a separate document.

# Module Description

## Materials:

* Stopwatch
* Infrared Thermal Sensor; (e.g., General Tools IRT207 Infrared Thermometer, ~$30)
* Dishpan or tub with cold water (~15oC), at least 10 cm deep
* Thermometer (in Celsius, for water baths)
* Ice
* Towels
* Heart Rate Monitor (optional); (e.g., Pyle PHRM36 Heart Rate Monitor, ~ $40)

## Preparation:

Preparation is minimal: teachers might want to set up the cold-water tubs in advance to save time, but this is not absolutely necessary. This lab works best if students are in groups of 3-4, and if each student is given the opportunity to “dive”. Students should be told beforehand that they will be submerging their faces in water and are encouraged to dress appropriately.

## Timeline:

**Part 1:** Demonstrating the Dive Response – 15 minutes

**Part 2:** Identifying factors that trigger the response – up to 1 hour, depending on students’ creativity and nature of their experiments

**Cleanup**: 20 minutes

**Analyzing Results and Creating Figures**: ~1 hour

## Starting Point For Inquiry:

Start by having all students hold their breath in air and record the time (in seconds) each student can hold it. The instructor then makes a histogram to show the distribution of maximum breath hold times among students in the classroom. Next, the instructor compares these values to the maximum breath hold times for marine mammals:

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| **Animal** | **Maximum Depth** | **Maximum Time** |
| Elephant seal | 1500 meters | 120 minutes |
| Blue whale | 500 meters | 60 minutes |
| Sperm whale | 1200 meters | 60 minutes |
| Blainville’s beaked whale | 1250 meters | 57 minutes |

Compare these values to the world record for humans, set in 2012 by Tom Sietas (a German free diver). He held his breath underwater for 22 minutes, 22 seconds. The instructor then introduces the notion that marine mammals spend a large part (if not all) of their lives under water. Being mammals, they all have lungs and require air to breathe. Ask students to brainstorm ideas on how mammals might cope (either physiologically or behaviorally) with living in aquatic environments, especially when it comes to diving underwater for extended periods. Encourage them to think critically about how changes in access to air (and thus stress) might influence oxygen consumption.

Introduce the mammalian dive response, and the three characteristics that are generally observed: *apnea, bradycardia,* and *peripheral vasoconstriction*. Explain how each of these responses help contribute to surviving underwater. Tell the students that this response is found most strongly in diving marine mammals, but also exists in many terrestrial mammals, including humans. Encourage the students to start generating ideas about why, and how, the dive response might be triggered in humans.

## Detailed Procedure:

**Part 1**. **Demonstrating the Dive Response**

* 1. Fill a tub with cold water (15°C) and use the thermometer to record water temperature (in °C). Get the temperature as close to 15°C as possible.
  2. **Control Phase**: The subject should sit with his/her face out of the water and breathe normally.
     1. Record the subject’s resting heart rate: place two fingers (do not use thumbs!) over either the radial (wrist) or carotid (neck) arteries and count the number of beats in 5 seconds. Multiply this number by 12 to find the subject’s heart rate in beats per minute (bpm). Record the heart rate in the data table.
     2. Use the infrared thermal sensor to record skin temperature (in °C) at a peripheral location (e.g., the palm of the hand).
     3. Use the infrared thermal sensor to record skin temperature (in °C) at a “core” location (e.g., the belly or back).
  3. **Simulated Dive Phase**: The subject should take a deep breath, then submerge his/her face in the water to the level of the temples, and remain in that position for 30 seconds.
     1. During the last 5 seconds of the dive, record the subject’s “diving” heart rate by again placing two fingers over either the radial or carotid arteries and by counting the number of beats in 5 seconds. From this number, calculate and record the subject’s heart rate in beats per minute (bpm).
     2. Record skin temperature at the peripheral location (in °C).
     3. Record skin temperature at the core location (in °C).
  4. Repeat steps 2 and 3 twice more to get three total trials. You can have the same person do the “dive” all three times, or you can use multiple subjects.

**Part 2. Identify Factors that Trigger the Dive Response**

1. You and your group will now conduct your own experiments to determine which factors trigger the dive response in humans. To keep things simple, focus only on bradycardia as an indicator of the dive response in your experiments. Think carefully about the conditions in which the subject already did the dive. How cold was the water? How long did the subject hold his/her breath? What was the position of the subject’s body? Before you begin the experiment, make some predictions. What factor(s) do you think will trigger the dive response in humans? Do you think one factor do you think is more important than others for triggering dive response?
2. Be creative! A good starting point is to test the response with the subject holding their breath in air versus with his/her face in water. You should conduct three or more experiments to test different triggers.
3. Before you begin the experiment, make some predictions.
   1. What factor(s) do you think will trigger the dive response in humans?
   2. Which factor do you think is most important for triggering dive response?
4. Each experiment should include a control measurement and a measurement of the experimental condition. You should test a single factor each time. In other words, only one thing should differ between the control and the experimental condition, or you will not be able to interpret your data. Before you begin your experiments, your teacher must approve each of them. This is for your safety.
5. When you think you’ve identified a trigger, repeat the experiment, ideally with more than one subject.

Recording and Analyzing Variation:

At minimum, students must record heart rate before (control) and after simulated dives. The dive response is characterized by a clear reduction in heart rate after a dive, generally 10-25% (Speck and Bruce, 1978). This can be represented by drawing bar graphs of average heart rate (1) during control periods, and (2) after simulated dives. Advanced students may conduct a paired *t-*test to test whether the average heart rate was significantly lower after their simulated dives.

## Assessment Methods:

Students must demonstrate that they isolated at least one factor that triggered the dive response. In humans, the dive response is triggered specifically by cold water contacting the face (Speck and Bruce, 1978). This response is neither triggered by water that is warmer than 21oC nor by submersion of body parts other than the face (Speck and Bruce, 1978).

The instructor may choose to have students compose a formal lab report (consisting of an Introduction, Background Research, Hypotheses, Materials & Methods, Results, and Discussion) or simply report results orally. In either case, the students should construct bar graphs of average heart rate to contrast control and experimental conditions, and may include statistical analysis using a paired *t-*test.

## Possible pitfalls:

Don’t forget to bring a towel!

The simulated diving sessions could be potentially dangerous if subjects do not know how to gauge their own breath-holding limits under water. Please encourage students to stop any trials immediately if the subject shows any signs of discomfort.

## Glossary:

**Apnea –** temporary cessation in breathing

**Bradycardia –** slowness of heart rate from resting heart rate (RHR) condition

**Control –** a standard of comparison for understanding the results of an experiment

**Hypothesis –** a proposed explanation for an observed phenomenon that can be tested

**Metabolism –** the chemical processes occurring within a living cell or organism that are vital to the maintenance of life

**Myoglobin –** an iron-containing protein found in muscle fibers that is functionally similar to hemoglobin but has a higher affinity for oxygen

**Peripheral Vasoconstriction –** decrease in diameter of blood vessels in auxiliary (typically appendicular) body parts.

**Variable –** a factor or condition that is subject to experimental change, especially to test a hypothesis

# Science Education Standards Addressed

**National Science Standards (NSES)**

A. Science As Inquiry (p.173-176)

C. Life Science (p. 181-187)

E. Science and Technology (p.191-193)

**California Public Schools Standards (SCSCPS)**

Biology-Life Sciences**,** 9. Physiology: As a result of the coordinated structures and functions of organ systems, the internal environment of the human body remains relatively stable (homeostatic) despite changes in the outside environment.

**a.** Students know how the complementary activity of major body systems provides cells with oxygen and nutrients and removes toxic waste products such as carbon dioxide (p. 46).

Investigation and Experimentation, 1. Scientific progress is made by asking meaningful questions and conducting careful investigations. As a basis for understanding this concept and addressing content in the other four strands, students should develop their own questions and perform investigations. Students will:

1. Select and use appropriate tools and technology (such as computer-linked probes, spreadsheets, and graphing calculators) to perform tests, collect data, analyze relationships, and display data.
2. Identify and communicate sources of unavoidable experimental error.
3. Identify possible reasons for inconsistent results, such as sources of error or uncontrolled conditions.
4. Formulate explanations by using logic and evidence.

**j.** Recognize the issues of statistical variability and the need for controlled tests.

**k**. Recognize the cumulative nature of scientific evidence.

**l.** Analyze situations and solve problems that require combining and applying concepts from more than one area of science.

NSES (<http://www.nap.edu/catalog/4962.html>)

SCSCPS (<http://www.cde.ca.gov/be/st/ss/documents/sciencestnd.pdf>);

# Guide to supplemental materials

**Lab Worksheets:** A document entitled “Hold Your Breath Student Worksheet” for student use during the lab

**Videos:** A short (2 min) video that outlines the lab, for use by instructors