The Diving Reflex in Humans

The diving reflex is an adaptation found in marine mammals for diving in cold water. The diving reflex is a reduction in heart rate, *bradycardia*, while diving. The majority of research on the diving reflex has been done on seals. The Weddell seal of Antarctica is a great example (Figure 1). Weddell seals can hold their breath for extended periods (20 minutes to an hour) and can dive to depths of 500 meters. During each dive, heart rate and cardiac output decrease dramatically in the Weddell seal, as blood is shunted away from the extremities and directed to the vital organs.

Figure 1

A much smaller version of the diving reflex occurs in all mammals and is easy to observe in humans. When cold water ($\leq$10° C) contacts the face or inside of the nose, sensory neurons are activated that increase parasympathetic activity. Breathing is inhibited and heart rate decreases, producing the diving reflex. This response is not observed during normal breath holding in air or during simulated dives in warm water. The diving reflex can also be influenced by learning. Cold water swimmers or experienced skin divers may have a larger diving reflex than other subjects.

OBJECTIVES

In this experiment, you will

- Obtain graphical representation of the electrical activity of the heart and respiration over a period of time.
- Calculate the heart-rate before and during a normal breath hold.
- Calculate the heart-rate before and during a simulated dive in cold water.
- Test the hypothesis that the diving reflex is elicited by cold water contacting the face

MATERIALS

computer	Vernier Gas Pressure Sensor
Vernier Computer Interface	Stainless Steel Temperature Probe
Logger *Pro*	Large bowl or basin
Vernier EKG Sensor OR Hand Grip Heart Rate Monitor	Large towel warm and cold water
electrode tabs	ice cubes
Respiration Monitor Belt	

PROCEDURE

Part I Baseline Heart and Respiratory Rate

1. Connect the EKG Sensor to Channel 1 and Gas Pressure Sensor to Channel 2 of the Vernier computer interface. Connect a Stainless Steel Temperature Probe to Channel 3 of the Vernier computer interface.

2. Select one member of the group as the test subject. Wrap the Respiration Monitor Belt snugly around the test subject's chest. Press the Velcro strips together at the back. Position the belt on the test subject so that the belt's air bladder is resting over the base of the rib cage and in alignment with the elbows as shown in Figure 2.

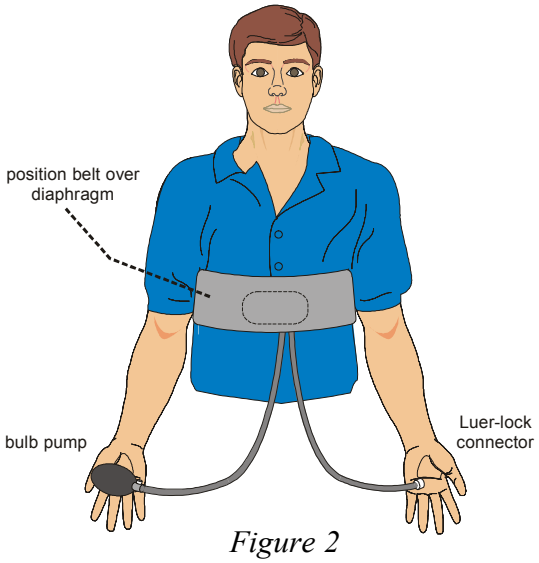


Figure 2

3. Attach the Respiration Monitor Belt to the Gas Pressure Sensor. There are two rubber tubes connected to the bladder. One tube has a white Luer-lock connector at the end and the other tube has a bulb pump attached. Connect the Luer-lock connector to the stem on the Gas Pressure Sensor with a gentle half turn.

4. Have the test subject sit upright in a chair. Close the shut-off screw of the bulb pump by turning it clockwise as far as it will go. Pump air into the bladder by squeezing on the bulb pump. Fill the bladder as full as possible without causing discomfort for the test subject.

5. The pressure reading displayed in the meter should increase about 6 kPa above the initial pressure reading (e.g., at sea level, the pressure would increase from about 100 to 106 kPa). At this pressure, the belt and bladder should press firmly against the test subject's diaphragm.

6. Attach three electrode tabs to the arms of the test subject, as shown in Figure 3. Connect the leads of the EKG sensor test to the electrode tabs as shown in Figure 3.

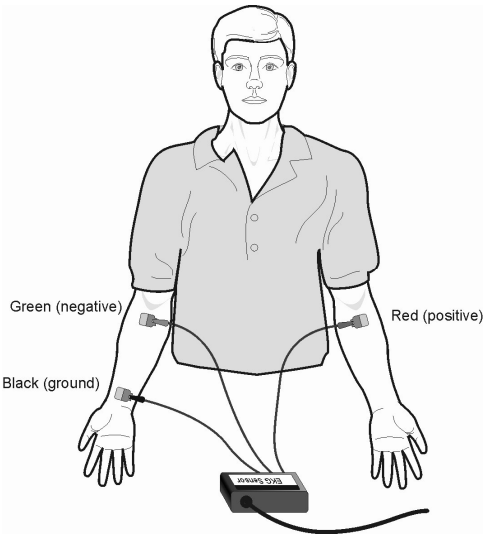


Figure 3

7. Have the test subject sit in a relaxed position in a chair. The forearms should rest on the legs or arms of a chair. When the subject is properly positioned, have someone click Collect to begin data collection.

8. Once data collection is finished, calculate the subject's heart rate in beats/min using the EKG data. Determine the respiratory rate and waveform amplitude from the test subject over a 1 minute period. Record this data in Table 1.

Part II Holding of Breath

1. Instruct the test subject to breathe normally. Start collecting data by clicking Collect. When data has been collected for 50 seconds, have the test subject hold his or her breath for as long as they can (30-45 seconds should be long enough). The test subject should breathe normally for the remainder of the data collection once breath has been released.

2. Determine heart rate before and during the breath-hold. The breath-hold should be very clear in the respiratory data. Calculate the subject's heart rate during the last 20-30 seconds of the breath hold. Record this data in Table 2. Calculate the percent change in during the breath hold. Record this data in Table 2.

3. Determine the respiratory rate and amplitude from the test subject before and after the breath hold. Record this data in Table 2. Calculate the percent change in respiratory rate and amplitude during the breath hold. Record this data in Table 2.

Part II The Diving Reflex

1. Fill a large bowl or basin with water. Place several ice cubes in the bowl. Record the temperature of the water with the temperature probe. Add ice cubes until the temperature of the water is approximately 10°C. The cold bowl of water should be placed in front of the subject. Record the temperature of the water in Table 4.

2. Instruct the test subject to breathe normally. Start collecting data by clicking Collect. When data has been collected for 50 seconds, have the test subject hold his or her breath and then place their face as far as they can in the basin of water. They should hold their breath for as long as they can (30-40 seconds should be long enough). The test subject should breathe normally for the remainder of the data collection once the simulated dive is completed.

3. Determine the subject's heart rate before the dive and then calculate the subject's heart rate during the last 20-30 seconds of the dive. Record this data in Table 3. Calculate the percent change in hear rate during the simulate dive. Record this data in Table 3.

Part III The Diving Reflex in Warm Water

1. Fill a large bowl or basin with warm water. The water needs to be at or exceed 23°C before conducting this experiment. The warm bowl of water should be placed in front of the subject. Record the temperature of the water in Table 4.

2. Instruct the test subject to breathe normally. Start collecting data by clicking Collect. When data has been collected for 50 seconds, have the test subject hold his or her breath and then place their face as far as they can in the bowl of water. They should hold their breath for as long as they can (20-30 seconds should be long enough).

3. Determine the subject's heart rate before the dive and then calculate the subject's heart rate during the last 20-30 seconds of the dive. Record this data in Table 4. Calculate the percent change in hear rate during the simulated dive. Record this data in Table 4.

DATA AND CALCULATIONS

Table 1 – Resting Parameters	
Resting heart rate	_____ beats / min
Resting respiratory rate	_____ breaths / min
Resting respiratory amplitude	_____ kPa

Table 2 – Breath Hold in Air		
	Before Breath Hold	After Breath Hold
Heart rate (HR)	_____ beats / min	_____ beats / min
Respiratory rate	_____ breaths / min	_____ breaths / min
Respiratory amplitude	_____ kPa	_____ kPa
Percent Change in Heart Rate $((HR_{during} - HR_{before}) / HR_{before}) \times 100$		_____ %
Percent Change in Respiratory Rate $((RR_{after} - RR_{before}) / RR_{before}) \times 100$		_____ %
Percent Change in Respiratory Amplitude $((RA_{after} - RA_{before}) / RA_{before}) \times 100$		_____ %

Table 3 – Simulated Dive in Cold Water		
	Water Temp	_____ °C
	Before dive	During dive
Heart rate	_____ beats / min	_____ beats / min
Percent change in heart rate $((HR_{during} - HR_{before}) / HR_{before}) \times 100$		_____ %

Table 4 – Simulated Dive in Warm Water		
	Water Temp	_____ °C
	Before dive	During dive
Heart rate	_____ beats / min	_____ beats / min
Percent change in heart rate $((HR_{during} - HR_{before}) / HR_{before}) \times 100$		_____ %

QUESTIONS

1. Did the heart rate of the test subject change after holding his or her breath? If so, describe how it changed.

2. What is different about the size (amplitude) or shape (frequency) of the respiratory waveforms following the release of the test subject's breath? Explain.

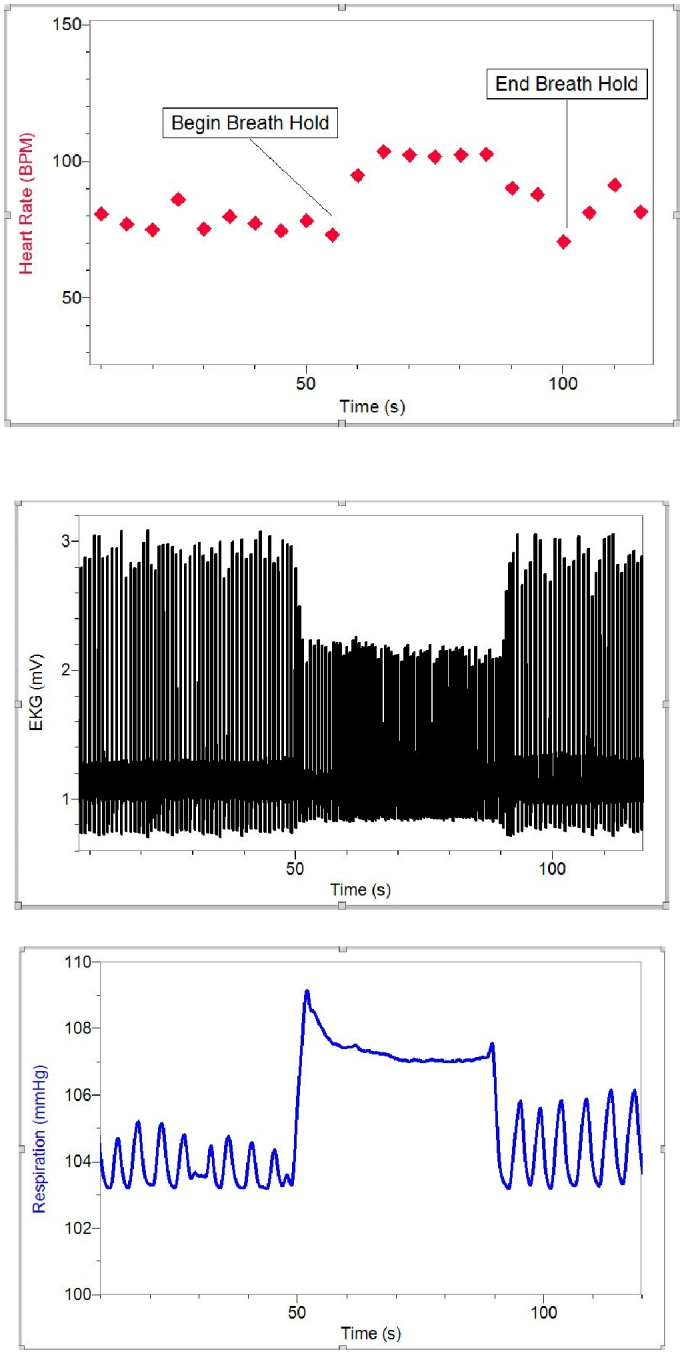
3. Did the heart rate of the test subject change during the simulated dive in cold water? If so, describe how it changed. Did you observe a diving reflex?

4. Did the heart rate of the test subject change during the simulated dive in warm water? If so, describe how it changed. Did you observe a diving reflex?

5. Which experiment tested the hypothesis that the diving reflex is elicited by cold water contacting the face? Explain?

SAMPLE DATA

Holding Breath (in Air) Increases Heart Rate

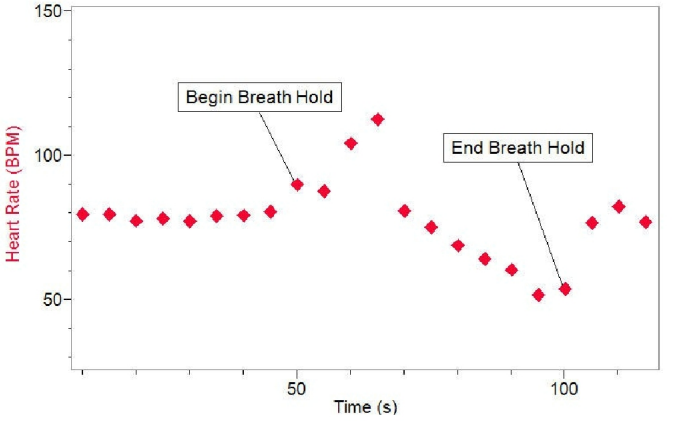


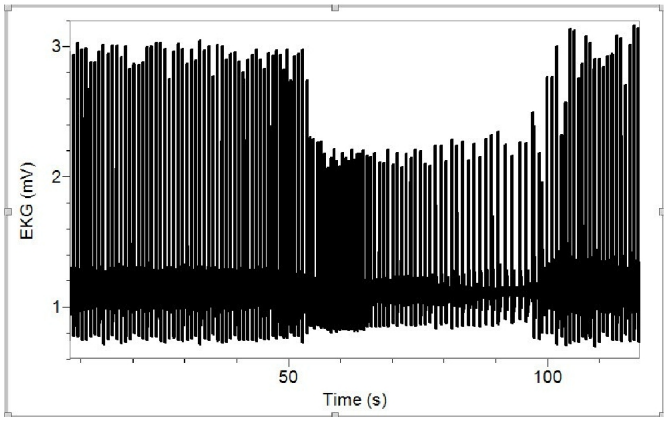
Increased Heart Rate During Breath Holding.

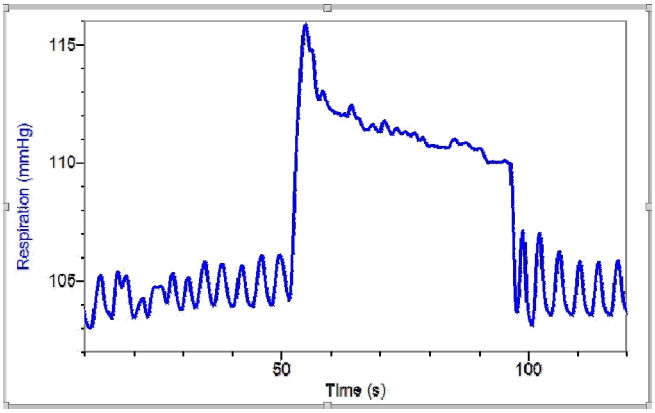
These sample data show a distinct increase in heart rate (HR) during a normal breath hold. The breath hold begins at 50 seconds and ends at about 90 seconds on each trace. The increase in HR is most pronounced at 60 seconds, which is 10 seconds after the breath hold begins. The response is also clearly visible in the Raw EKG trace. Each 'spike' represents the QRS complex in the EKG. The spacing of the spikes before, during and after the breath hold clearly shows heart rate increases

during the breath hold. The last figure is a trace using the respiratory belt. Each upward deflection is an inhalation and each downward deflection is an exhalation. The breath hold can be clearly seen from 50-90 seconds, which is essentially a deep inhalation that is held for as long as possible. Increased depth of inhalation and exhalation is clearly visible in the trace after the breath hold.

Simulated Dive in Cold Water Decreases Heart Rate

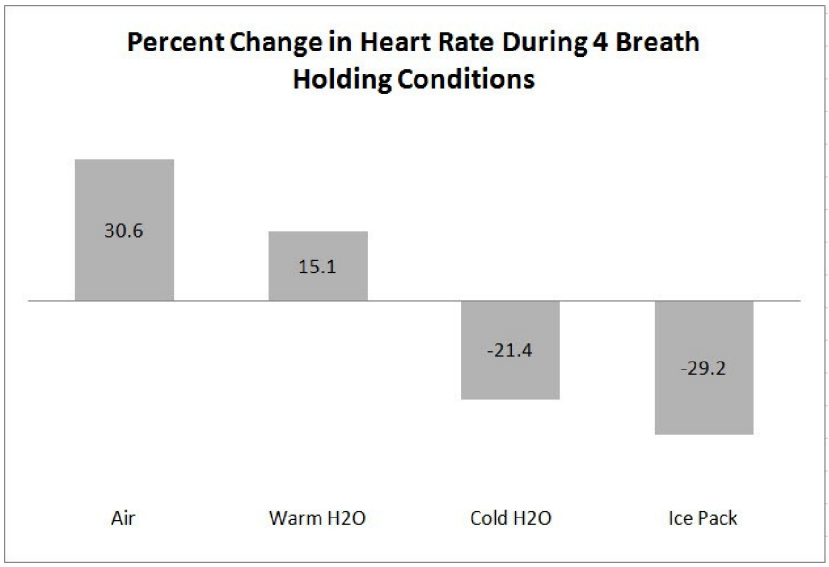






Heart Rate Decreases During a Simulated Dive in Cold Water.

These sample data show a distinct decrease in heart rate during a simulated dive in cold water (< 10°C). The breath hold begins at 50 seconds and ends at about 90 seconds on each trace. The response is most pronounced between 70-90 seconds, which is 20 seconds after the beginning of the dive. The transient increase in the heart rate at the beginning is likely due to the shock of the cold water on the face. The decrease in HR is also clearly visible in the Raw EKG trace. The spacing of the spikes before, during and after the breath hold clearly shows a heart rate decrease during the breath hold. The last figure is a trace using the respiratory belt. Each upward deflection is an inhalation and each downward deflection is an exhalation. The breath hold is clearly seen from 50-90 seconds. Increased depth of inhalation and exhalation is clearly visible in the trace after the breath hold.



Cold stimuli are required to elicit the diving reflex.

The graph above shows the percent change in heart rate (HR) during 4 different breath holding conditions. A breath hold in air produced a 30.6% increase in HR in this individual. Placing the face in warm water (22 °C) produced a 15.1% increase in HR, as opposed to placing the face in cold water (4 °C) which produced a 21.4% decrease in HR. Cold receptors on the face appear to 'trigger' the diving reflex. In the last case, placing a cold pack on the face (-4 °C) during a breath hold produced a 29.2% decrease in HR. Taken together; these data suggest that only cold stimuli elicit the diving reflex.

