

The Nervous System: Reaction Time

Teacher Version

California Science Content Standards:

- **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.**
- 9b. Students know how the nervous system mediates communication between different parts of the body and the body's interactions with the environment.
- **9c. Students know how feedback loops in the nervous system [and endocrine] system(s) regulate conditions in the body.
- **9d. Students know the functions of the nervous system and the role of neurons in transmitting electrochemical impulses.
- **9e. Students know the roles of sensory neurons, interneurons, and motor neurons in sensation, thought, and response.

Materials:

- 1 meter stick for every 2 students (or fewer if they work in larger groups)
- Calculators (or the calculating function on students' cellular phones)
- Computers (running MacOS or Linux), with python installed and a working mouse
- Headphones recommended if using more than one computer at a time
- Penlight or small flashlight (1 or 2)
- Place where students can sit so that their legs dangle freely
- Piece of cardboard

Prerequisites:

Basic version: Students are expected to use a calculator to take averages and square roots.

Advanced version: Students are expected to know how to take averages and square roots and to use the formula $\text{distance} = \text{rate} * \text{time}$. One question in Part 3 requires knowledge of basic trigonometry. The advanced version includes more concept questions, some of which can be answered with names of specific nerves and muscles (eg: "optic nerve") by those studying anatomy, or can be answered more generically (eg: "nerve connecting your eyes and your brain") by others.

Key Concepts:

- Your nervous system allows your body to react to different **stimuli** (external events)
- Reactions can be **voluntary** (eg: swinging a bat at a ball flying at you) or **involuntary** (eg: blinking at a puff of air)
- A **reflex** is a rapid, automatic response to a stimulus
 - examples: shivering if the temperature is too cold; moving your hand if it gets too close to a hot surface.
- Reflexes require at least two **neurons**, or nerve cells, to function. **Sensory neurons** take in information (**input**) from the outside world, whereas **motor neurons** give information (**output**) to muscles and joints.
- Some reflexes are processed in the brain, while others are processed in the spinal cord
- The 5 steps of a typical **reflex arc** are:
 - a. Arrival of stimulus and activation of a receptor
 - b. Activation of sensory neuron

- c. Information processing by interneuron
- d. Activation of a motor neuron
- e. Response by an **effector** (the muscle that carries out the response)

Introduction:

Suppose a ball is thrown toward your head. You may react by catching the ball, by ducking, or by blinking and turning your head. In each case, you must sense the arrival of a signal (i.e. the sight of the ball flying towards you), process this information and react to it. In this lab, you will explore how your nervous system allows you to react to signals from the world around you. You will measure your reaction times to various visual and auditory stimuli and observe the effects of several variables on these reaction times. You will also elicit and observe some innate reflexes. The lab consists of three stations, to be done in order. In the **Ruler Station**, you measure your reaction time by catching a falling ruler. In the **Computer Station**, you will use an application that tracks your reaction time to visual and auditory stimuli. In the **Reflex Station**, you will observe a couple of innate reflexes that are often used for diagnostic purposes. Each section contains questions for discussion.

To set up the computer-based reaction timer:

1. Unzip the archive rxntimelab.zip
2. Open up a terminal window and go into the rxntimelab directory.
3. Type “python rxntimer.py”
4. Make sure the volume is turned up on the computer

Part 1 – Ruler Station

Materials:

- Metric ruler, calculator

Holding your thumb and index finger about 4 cm (1.5 in) apart, catch the ruler when your partner drops it. Do 5 practice runs without recording the results.

Now record the results for 3 more trials of the experiment.

Repeat the experiment holding your fingers 10 cm apart. Record your results in the chart below.

Repeat the experiment saying every other letter of the alphabet while waiting for the ruler to drop. Record your results.

	4 cm	10 cm	Alphabet (4 cm)	Key Word (4 cm)
Trial 1	cm	cm	cm	cm
Trial 2	cm	cm	cm	cm
Trial 3	cm	cm	cm	cm
Average length	cm	cm	cm	cm
Reaction time	sec	sec	sec	sec

To calculate the average length, use the formula **length = (trial 1 + trial 2 + trial 3) ÷ 3**

To calculate the reaction time, use the formula: $time = \sqrt{length / 490}$

(Note: this formula takes length in units of cm and gives time in units of seconds)

Typical reaction times for the ruler experiment should be on the order of 0.2 sec.

Is there a difference in the calculated reaction time between the 4 cm and 10 cm trials? Which one seems to be faster? Why do you think this is? What could you learn from a series of experiments where the subjects' fingers start at different separations?

The reaction times will generally be slightly longer with the fingers starting 10cm rather than 4cm apart since it takes longer to move them by that distance. By doing a series of such experiments, you could get an estimate of the time required to react to the stimulus versus the time required to actually move the fingers together once the signal to grasp has been received.

Did your reaction time increase or decrease while you were saying the alphabet? Explain why you think this happens.

Reaction should increase slightly due to the distraction.

Now repeat the experiment with the following twist: only catch the ruler when your partner says the key word “**monkey**”. Be sure to say the word *before* dropping the ruler. Your partner should try to trick you by occasionally dropping the ruler while saying other, incorrect, words. (For instance, if the experimenter says “banana” and then drops the ruler, don’t catch it!). Keep trying until you catch the ruler 3 times in a row on the correct word WITHOUT any mistaken catches on the wrong word. Record the length at which the ruler was caught for those three times.

Did your reaction time increase or decrease? Explain why.

In this case, the reaction time includes not only the time required to process the auditory and visual stimuli, but the decision if it is correct or not (recognition time). Thus, the overall reaction will be slower.

Ruler station concept questions:

1. Consider the 5 steps of a reflex arc (see first page). What are the components of the neural system involved in each of the 5 steps for the specific case of the subject catching the ruler?

(a.) visual stimulus activates photoreceptors (b.) the sensory optic nerve is activated (c.) information is processed in the midbrain (d.) the median nerve (a motor neuron) carries the signal to the hand (e.) muscles in the hand cause the fingertips to come together

2. You answered several questions asking if there was a difference between two runs of the experiment. Of course, no two measurements will ever come out identically the same. Explain how you would determine whether the difference between two runs of the experiment is significant (meaningful) or not?

In addition to the average reaction times, one should also get a measure of how much the times vary: the standard deviation. If the difference between the reaction times in two runs of the experiment is greater than a standard deviation or so then this is most likely due to a real underlying difference in the reaction times rather than just variability in the experiment.

Part 2 – Computer Station

Materials:

- Computer with functional speakers and a mouse
- Headphones for each computer, if multiple computers are used

The reaction timer should already be open on your laptop. Ask your teacher if you can't see it.

Visual: Click on the “Visual” button near the top of the window. You should see two gray circles and a button labeled “Start” to the right of them. Click on the Start button. The top circle will turn red and the timer will wait for a few seconds. As soon as you see the red light on top switch to a green light on the bottom, click and release the button (now labeled “End”). The timer will record your reaction time in the table to the left. If you click the End button before the light turns green, that test will not count. If you want to erase the last recorded time, click on the Undo button at the bottom. **Do a few practice runs first. Then record the average of 5 trials.**

	Visual	Auditory: loud	Auditory: soft	Decision
Average:	sec	sec	sec	sec

How does your reaction time, as measured in this experiment, compare with the reaction times calculated in the first part of the ruler-drop section? Are they close? Why might there be differences?

The reaction times should be similar for both the computer and the ruler drop experiment. Differences could be due to the different movements required to actually respond to the stimuli (ie: pressing and releasing the mouse button vs bringing fingers together to catch the ruler). Ruler-catching times might also be slightly shortened if the subject can see when the experimenter is about to drop the ruler.

Auditory: Now click on the button labeled “Auditory” to record your reaction time to an auditory stimulus. Again, click on the Start button to start the test. The light will turn red, the computer will wait a few seconds and then produce a beep. If you do not hear a beep for more than 10 seconds, make sure that the volume on the computer is turned up. As soon as you hear the beep, click on the big button again and your reaction time will be recorded. Record your results in the chart above.

Run the auditory test first with the volume turned up to produce a loud beep, then with the volume turned down for a softer (but still audible beep).

Was there a difference between your average reaction time for the visual and the auditory stimuli?

Auditory reaction times, at least for loud stimuli, tend to be slightly shorter than visual ones. This is not the case for quieter stimuli, however.

Did you notice a difference in your reaction times for loud versus soft stimuli? Why do you think a louder beep might lead to shorter (or longer) times?

A louder beep should shorten the reaction time. Your ear integrates the sound waves over a period of time up to 0.1 sec. A louder beep requires a shorter amount of time to reach the

minimal overall level of stimulus necessary to trigger a reaction.

Decision: Now click on the button labeled “Decision”. Click the Start button to run the test. After a short pause, a picture will appear on the screen. Click the End button **only** if it is a picture of a cat. If the picture does not show a cat, it will disappear on its own in 2 seconds, or you can click on the Clear button to reset the test. Repeat until you measure 5 reaction times where you correctly clicked on the cat pictures only. You must click on the Start button each time, regardless of whether the picture showed a cat!

Which ruler drop experiment do you expect to yield similar times to the ones obtained here? Why are the two experiments analogous? Are the times, in fact, similar?

In this experiment, you have to process a stimulus and recognize whether or not it is the right one before responding to it, so this is comparable to the last section of the ruler drop experiment. There are many possible explanations for any differences however, including the fact that an auditory recognition stimulus was involved in the ruler experiment, whereas everything on the computer is visual.

Computer station concept questions:

1. Consider again the 5 steps of a reflex arc.

(a) Which component(s) changed between the first ruler-drop experiment and the first experiment in this section?

the precise effector muscles, the finer motor neurons that direct exactly how your fingers move

(b) Which component(s) changed between the “visual” and “auditory” trials in this section?

the sensory receptors, and sensory nerve

(c) Which component(s) changed between the “visual” and “decision” trials in this section?

the neurons involved in processing the information

2. (a) Use the data obtained in this experiment (or in the ruler station) to make a rough estimate of the average rate of signal propagation in your nervous system

A signal has to go from the screen to your eye (or ear), be processed in your brain, and then travel to your fingertips to press the mouse button. The overall distance that the neural impulses must cover is on the order of 1 m. This takes approximately 0.2 sec (or whatever times were measured).

Time = distance / rate

So the average rate of signal propagation is about 5 m/s.

(b) This rate is an average over several physiological events. List some of these.

(Note: this question is for students with some knowledge of the nervous system, though it can be answered in more generality by others)

This rate includes: response of the sensory cell (rods/cones in eye or hair cells in ear) to the stimulus, transmission of signal across synapses between neurons, transmission of the action potential along a single neuron, and contraction of finger muscles in response to the signal.

3. Come up with another variable in the presented stimulus (eg: color of the dot, duration of the beep, etc.) that you think would influence the reaction times, and explain why you think the reaction times would differ? Would you expect the times to get longer or shorter using the modified stimulus you're proposing?

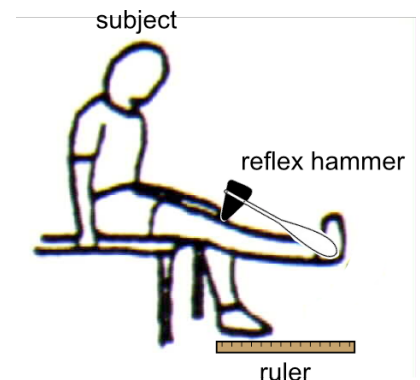
At low volume, having the beep last longer may lead to shorter reaction times due to the time-integration of the auditory stimulus. Similarly, since the human ear has different sensitivity to different frequencies, changing the frequency of the beep while keeping the volume constant should also affect the reaction time (whether it increases or decreases depends on how close the frequency is to the optimal frequency for human ears). There are many other possible answers here.

Part 3 - Reflex Station

Materials:

- Penlight or small flashlight
- Meter stick
- Someplace to sit where legs can dangle freely

Work in teams of 3 – the subject, the experimenter, and the data recorder. The subject should sit on a desk or someplace where his/her legs can dangle freely. The experimenter should try to elicit the **patellar reflex** (also known as the knee-jerk reflex). This reflex is processed in **your spinal cord and not in your brain!** Using the side of your hand, tap one of the subject's legs just below the kneecap. You should not need to hit very hard! By looking straight down at the ruler, the data recorder should measure the horizontal distance that the foot travels relative to the height at the bottom. Trade roles so that all of you have a chance to be the subject.



	Trial 1	Trial 2	Trial 3
Distance of kick			
Angle of kick			

Work out a formula for determining the angle of the kick given the height that you measured (if you haven't done trigonometry, ask the teacher or an older student for help). Why might the angle rather than the height be a more useful measurement of the magnitude of the response?

The formula is $\sin(\text{angle}) = (\text{measured distance of kick}) / (\text{length of leg})$. The angle is a more useful measurement because it does not depend on the length of the leg. Tall and short people with the same reaction will kick to a similar angle but the length will be longer for the taller person.

Is this a voluntary or involuntary reaction? Are you able to stop yourself from kicking your leg?
This is an involuntary reflex.

What are some variables that might affect the magnitude (how high you kick) of the observed response?

Some possibilities are: being distracted, sleepy, or excited, age, how tired you are

Direct / consensual pupillary reflex: If possible, dim the lights in the room. Hold a piece of cardboard at your nose, separating your left and right eye. The experimenter should briefly shine the penlight in the your left eye (5-10 cm away from the eye) and observe the size of the pupil in the left eye. Wait a little while for the pupil to readjust and repeat the experiment, this time shining a light in the left eye while observing the right.

What happened to the pupil in each eye when you shone the light in the left eye? Is this a voluntary or involuntary reaction?

Both pupils should dilate in response to light. This is also an involuntary reflex.

Post-lab Questions

1. (a) What is the role of the pupillary light reflex? Why is it important to us?
(b) Can you think of a useful role for the knee jerk reflex?

(a) This reflex regulates the total amount of light hitting our photoreceptors. It helps protect against overexposure of the receptors and also to maintain visual sensitivity at a larger range of background light levels.

(b) This reflex can help maintain posture and balance. When the quadriceps is stretched, the brain responds by contracting it and relaxing the opposing muscle (the hamstring) to restore balance.

2. Why do we need to have innate reflexes at all? Why do we need involuntary reflexes? Wouldn't we be better off being able to control everything that our body does?

Innate reflexes allow your body to perform basic survival functions (blinking, breathing, etc.) without conscious thought, so that attention can be focused on other things. Involuntary reflexes can also be faster than voluntary ones since the signal doesn't have to go through processing centers in the brain (eg: the knee-jerk reflex only goes through the spinal cord).

3. Why do doctors measure reflexes during a diagnostic exam? What information can they get out of these measurements? Why is the knee-jerk reflex particularly useful for diagnosing the location of a problem in your nervous system?

Doctors measure reflexes to pinpoint the location of any damage to the nervous system. Loss of the knee-jerk reflex indicates damage to the femoral nerve and/or spinal nerves. Loss of either the direct or consensual pupillary light reflex can indicate damage in the optic nerve or the oculomotor nerve of one side (depending whether both the direct and the consensual response are gone). The knee-jerk reflex specifically is useful for determining whether the problem is in the brain or in the spinal chord or peripheral nervous system.

4. Based on data you measured in this lab, why is it a bad idea to talk on your cell-phone while driving?

We measured that reaction time increases when you are distracted. You will not be able to respond as quickly to sudden changes on the road.

5. The distance from the pitcher to the batter in a baseball game is about 60 feet. A fast-ball travels at approximately 100 miles per hour (147 feet per second).

How long (in seconds) does it take the ball to reach the batter after it is thrown?

$$60/147 = 0.4 \text{ seconds}$$

6. Suppose an insane pitcher decided to pitch a cat at you instead of a baseball. If you had your eyes closed until the instant when the pitcher let go, would you have time to react before the cat hit you in the face (compare to data you measured in this lab)?

The reaction times in the experiment where you had to determine whether a picture showed a cat were probably slightly greater than 0.4 seconds. So, unless you could see the pitcher throwing it before he let go, you wouldn't be able to notice the cat fast enough to react to it.

7. Based on data you measured in this lab, do you have enough time after the ball leaves the pitcher's hand to decide how the ball will fly and to aim for it? How do you think good baseball players manage to actually hit the ball?

Again, since judging the ball trajectory and aiming for it requires making decisions, you probably don't have time to respond after the ball leaves the pitcher's hand. However, good baseball players tend to judge how the ball will fly while the pitcher is throwing it, thereby buying themselves extra time. Also, reaction times can be brought down with practice, and professional sports players tend to have pretty fast reactions.