NATIONAL CENTER FOR CASE STUDY TEACHING IN SCIENCE

How Do Scallops Move?

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Part I – The Scallop

Survival often depends upon detection and escape from predators. Scallops are bivalves that live on the seabed and respond to the touch of a predator by quickly closing their shells (or valves) and moving away from the stimulus by jet propulsion. The two shells are joined at the hinge by a ligament composed of a rubber-like protein. Shells of dead scallops are often washed up on the beach. When they are connected, the two shells are usually found at an angle greater than that seen in living animals (Figure 1); this indicates that the rubber-like hinge not only joins the two shells, but also forces them apart. An adductor muscle is attached to the inside surface of each shell. When the adductor muscle contracts, the valves close and the hinge ligament is compressed; when the muscle relaxes, the elastic energy stored in the ligament is released and the shells reopen.

Figure 1. The shells of a bivalve. Without the adductor muscle, the hinge opens the shells to an angle greater than that seen in the living animal.

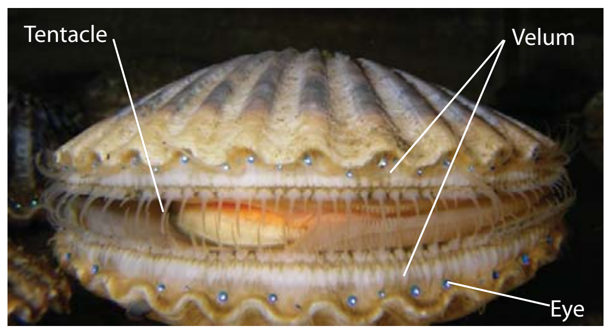

Figure 2. The margin of a living scallop has a muscular velum bearing eyes and tentacles.

If a predatory starfish touches the velum along the margin of the shell (Figure 2), most scallops rapidly contract their adductor muscle to force water from between the two shells and propel the animal off the seabed and away from the predator. Some scallops use a rhythmic series of alternate opening and closing movements of their shells to produce swimming. This case study examines the physiological basis of this simple behavior pattern.

Questions

1. How are the two shells of the scallop forced apart?
2. How are the two shells of the scallop closed?
3. Some scallops swim by rhythmically opening and closing their shells. What part of the animal produces the propulsive force for movement through the water?

Part II – Swimming

Scallop swimming is composed of a rhythmic series of alternate contractions and relaxations of the adductor muscle. Each muscle contraction closes the valves and forcefully expels water out of the mantle (body) cavity through jets on either side of the hinge (Figure 3). After each contraction, the muscle relaxes and the elastic energy stored in the hinge ligament opens the shells, ready for another contraction. In this way, the sequence of shell movements seen during swimming looks like the scallop is "biting" into the water. At the end of the swim, the shells slowly come closer together as the rapid shell movements cease and the animal sinks to the seabed. (See video at http://www.racerocks.com/racerock/eco/taxalab/ensy02/vdejesus.htm.)

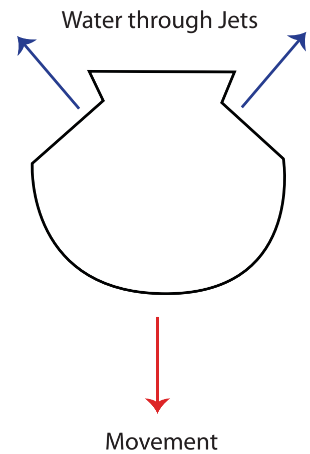

Figure 3. Swim direction.

Investigators devised a technique of tethering scallops by attaching a large plastic bolt to the underside of the shell using dental cement. The bolt is screwed into a plastic nut embedded in a weight at the bottom of a tank of circulating seawater. Thread is then used to connect the free shell to a displacement transducer so that valve movements can be monitored. The upper trace of Figure 4 shows a sample of a swimming sequence recorded from a tethered scallop.

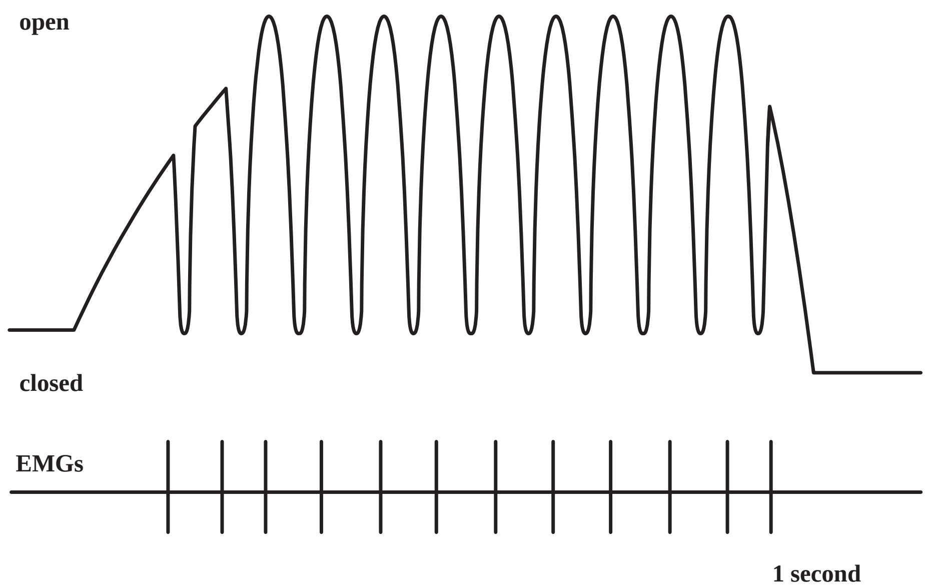

Figure 4. A swimming sequence recorded from a tethered scallop in response to the touch of a predatory starfish. The recordings show shell movements (upper trace) and electromyograms from the striated portion of the adductor muscle (EMGs, lower trace).

The single adductor muscle of the scallop is divided into two parts: the smooth and the (larger) striated. The investigators used thin insulated wire to record electromyograms (EMGs) from the striated adductor muscle; they observed that each rapid shell closure coincides with an action potential in the striated muscle (Figure 4). Therefore, they suggested that, during swimming, a single contraction of the striated portion of the adductor muscle closes the valves and propels the animal through the water. When the striated muscle relaxes, the energy released by the compressed elastic ligament opens the shells to allow more water into the mantle (body) cavity and stretches the adductor muscle before the striated muscle contracts again.

Questions

During this case you will construct a hypothesis to explain the pattern of muscle contractions seen during scallop swimming.

1. Draw a diagram to show the possible layout of the nerves and muscles involved in scallop swimming. Draw symbols to represent the brain, the striated portion of the adductor muscle, and the motor neurons to the striated muscle. Label your diagram and develop a hypothesis to explain the observation that swimming involves a rhythmic series of striated muscle contractions. You should consider the following questions:
   a. How is the power stroke for swimming produced?
   b. How many action potentials are required in the striated muscle to initiate a contraction and a closing of the shells?
   c. What is the role of the motor neurons in producing an action potential in the striated muscle?
   d. How is a rhythmic sequence of action potentials produced in the motor neurons to the striated muscle during swimming?
   e. Does shell opening play a role in the initiation of a motor neuron action potential, and a subsequent striated muscle contraction, during swimming?
2. Devise an experiment to test your hypothesis explaining the pattern of muscle contractions seen during scallop swimming.

Part III – How are Rhythmic Muscle Contractions Controlled?

The investigators used a Plexiglas rod to restrict shell opening in a tethered swimming scallop. The recording (Figure 5) shows that the rhythmic swimming sequence stops when the rod is lowered and restricts shell opening below a certain angle. Raising the rod allows the valves to open and swimming resumes.

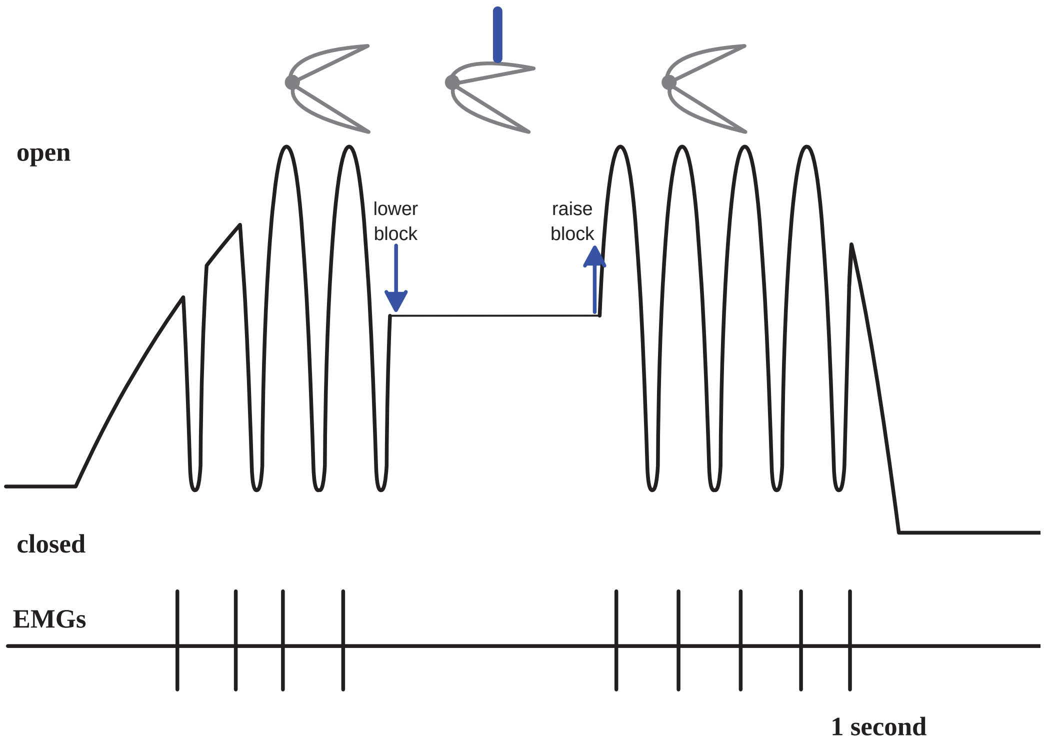

Figure 5. Shell movements and striated muscle EMGs recorded from a tethered swimming scallop. A Plexiglas rod was lowered onto the upper shell (downward blue arrow) to prevent full shell opening during swimming (central inset); this stopped the rhythmic shell movements and the EMGs. Swimming resumed when the rod was raised (upward blue arrow).

Questions

1. How does the block interfere with the swimming sequence?
2. How does your hypothesis explain how the block interferes with swimming?
3. Would you like to modify your hypothesis to explain how the nervous system controls the rhythmic striated muscle contractions observed during swimming?
4. Illustrate these modifications on your diagram by drawing a sensory element that detects the angle between the shells and indicating how the sensory neuron affects the motor neurons to the striated muscle.
5. Devise an experiment that will change the frequency at which the swimming scallop flaps its valves.

Part IV – Can the Frequency of Swimming Be Changed?

The investigators attached small pieces of a plastic sheet to the edges of the moving shell of a tethered scallop to slow the rate at which the shell opened. These animals exhibited a slower rate of rhythmic swimming.

They also removed small pieces of shell from the free valve of other scallops to provide less resistance to movement through the water; the swimming frequency increased.

Questions

1. What do the above observations tell you about the control of the rhythm of muscle contraction during scallop swimming?
2. Would you like to modify you hypothesis for controlling the rhythm seen during swimming? If so, why; or if not, why not?
3. Where do you think the sensory element is located?

Part V – How Is the Swimming Sequence Started and Stopped?

In scallops, the smooth portion of the adductor muscle contracts much slower than the striated and the investigators were not successful in recording electrical activity from the smaller, smooth muscle. However, the investigators showed that cutting the smooth muscle instantly and significantly increased the angle between the two shells, and the stretched striated muscle could not close the shells and keep them shut. The investigators explained these observations by assuming that the smooth muscle controls slow, postural movements of the valves.

Questions

1. If the investigators are correct and the swimming sequence is produced by a series of striated muscle contractions, do you think that the slowly contracting smooth muscle is contracted or relaxed during swimming?
2. The investigators found no evidence that the smooth portion of the adductor muscle contracts rhythmically during swimming. Recordings from tethered scallops showed that the initiation of the swimming sequence involves a slow opening of the shells and termination involves a slow closing. Can you speculate on the role of the smooth muscle in initiating and terminating the swimming sequence?
3. The smooth and striated portions of the scallop adductor muscle are supplied by different motor neurons. If the touch of a predatory starfish on the velum excites the motor neurons to the striated muscle (and initiates the rhythmic swimming sequence), what is the effect of the same stimulus on the motor neurons of the smooth muscle? Indicate your ideas on your diagram.
4. If you joined the team of investigators, what experiments would you perform to examine the control of scallop swimming?

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