PART 3

How does a blue whale feed?

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Lunging for dinner

All animals have to eat, but few do it as dramatically as rorquals. Their dining strategy, **lunge feeding**, is unique to rorquals—in fact, it's their defining characteristic.

Baleen whales use several kinds of filter feeding. Some non-rorquals, such as right whales and bowheads, use a feeding method called **continuous ram filtration** or skim feeding: They swim through prey-rich areas with their mouths partly open, taking in food and water. The continuous forward movement rams the water through a complex arrangement of lip features and baleen, then out through jetport-like openings at the corners of the whales' mouths, just beneath their eyes. Food gets caught on their baleen.

Rorquals, in contrast, are intermittent feeders. They would not be able to keep their vast bodies fed on the lower-concentration prey fields where right whales forage. Instead of continuously filtering prey out of a large tract of water, rorquals seek out highly concentrated prey patches and take a mouthful only when they've found one big enough and dense enough to tempt them. "If you're going to be a blue whale," says marine biologist David Cade, "in order to feed you have to find patches that are big enough, so that you can actually get enough energy from each one of those lunge feeding events."

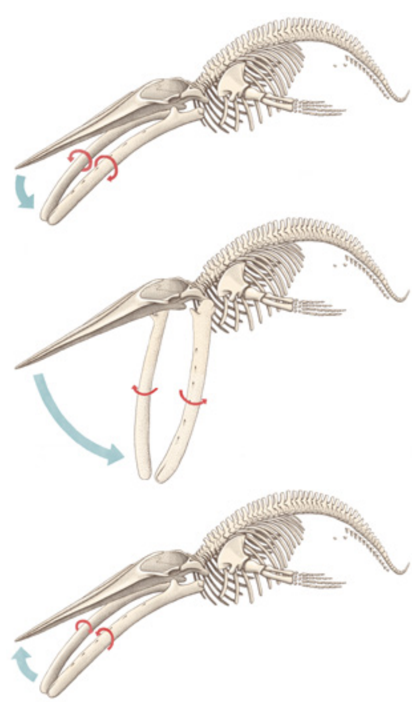

Figure 1. Pivoting jawbones.
As a rorqual opens its mouth, the two halves of its lower jaw separate slightly and pivot open; as it closes its mouth, the two halves pivot shut again. Illustration by Alex Boersma

Rorquals' jaw anatomy helps them take a big gulp. Unlike ours, their lower jaws are detached into two pieces, with a separation at the bottom of the U; where we have pointed chins, they have chins with unfused lower jawbones at the tip. When the whale opens its mouth to feed, the two halves of the U pivot apart like a partially closed book or greeting card opening wide to display its contents (**Fig. 1**). The motion adds volume to the enormously expanded pouch.

Rorquals' lunge feeding has three phases: **acceleration**, **engulfment**, and **filtering** (**Fig. 2**). During the acceleration phase, the whale must speed up enough for the water pressure to push its throat pouch open; it can accelerate from its typical speed of 1 to 2 meters per second (2.2 mph to 4.5 mph) to reach speeds of up to 3 or 4 m/s (about 9 mph). During the engulfment phase, which lasts about five seconds, its mouth closes on a gigantic gulp of prey-filled water. Then, in the filtering phase, the whale must expel the water, using its baleen to retain the prey. During the feeding season, the whale repeats these three phases hundreds of times a day.

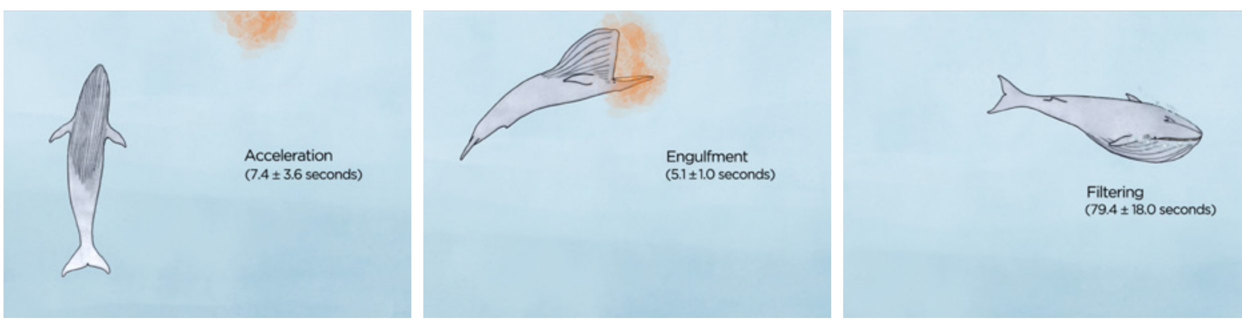

Figure 2. Lunge feeding. These images show a blue whale's movements as it performs the acceleration, engulfment, and filtering phases of its lunge. Illustration by Alex Boersma

The enormous intake of water (up to 140 percent of the whale's weight) slows the whale rapidly due to the drag caused by opening its mouth and adding the mass of the water to its own body mass. As the moving whale gulps still water, it transfers its momentum to the now engulfed water. In addition, the change in the whale's shape alters the flow of water around its normally streamlined body. "Remember that these whales are very **hydrodynamic**—they're shaped like torpedoes going through the water," says Cade. "So they can go really fast with minimal drag, but as soon as they open their mouth and start inflating like a parachute, that's going to slow them way down. It's going to take a lot of energy to push against that."

And remember—the whales are performing these energetic acrobatics while holding their breath, typically for 15 minutes at a time. "They're mammals, just like us," says Cade. "We need air to breathe; they need air to breathe. They can't get air from the water like a fish, so they have to return to the surface every so often. But the food is down deep, and so they have to have this continual contrast between going down to get food and then coming back up."

When a blue whale performs a complete dive—going down, performing its underwater activities, and returning to the surface to breathe again—it needs to maximize its feeding time. Each visit to the surface comes with a cost in time, energy, and effort, says Cade, so the fewer times a whale has to return to the surface and the more it can get done on each dive, the better.

To feed efficiently, rorquals have to time their lunge just right to take in as much krill or fish as possible. Some rorquals, such as humpback whales, are generalist feeders, preying not only on krill but also on fishes like sardines and anchovies, which can swim away; these generalists have to consider the fishes' evasion behavior, gulping them suddenly before they can escape. But blue whales are specialist feeders that eat only krill, which don't maneuver well. When rorquals go after krill, timing the lunge is less about catching animals that are trying not to be eaten, and more about making sure they capture enough food to make their lunges worth the expense of energy. If blue whales open their mouths too soon, they may engulf too much krill-poor water, wasting energy on a skimpy mouthful. If they open them too late, they may miss part of the rich krill patch.

The value of efficiency

Feeding efficiently is extremely important to blue whales because they have such enormous energy needs and specialize in just one type of food. It all comes back to the question of how they got to be so big. "If you're a very large animal, you have a lot of body mass that you have to maintain, and that requires a lot of energy, so you have to be very efficient in how you feed," says marine biologist Jeremy Goldbogen. "This lunge-feeding mechanism, we think, really drove the evolution of body size in these rorqual whales, and we think it's the key to why we see blue whales as the largest animals of all time." Blue whales' sole food resource, krill, "is only available on a very, very short time scale in the summer months," says Goldbogen. "It's very ephemeral. When the patches get dense and abundant in the summer months, blue whales have to be incredibly efficient to make the most out of a very short feeding season."

Lunge-feeding behavior has what may be the greatest energetic costs of all animals' feeding behaviors. A blue whale must constantly weigh the cost and benefit of its movement from the moment it goes underwater to the moment it comes up for air. As the Goldbogen team gathered data on whales' behavior underwater, they had many questions about the processes that underlie these extreme feeding mechanisms: How do the whales vary their speed while diving down, feeding, and returning to the surface? Do they swim at top speed when traveling through a prey patch? How about during the descent? At what point during the feeding process do they open and close their enormous mouths?

The data showed that blue whales feeding on krill followed a distinct pattern of activity. They opened their mouths at peak speed and closed them around the time they had lost enough momentum to return to normal speed. When the researchers tested different models of feeding for blue whales, they found that this pattern was the most efficient way to mitigate the energetic cost of engulfment.

The data

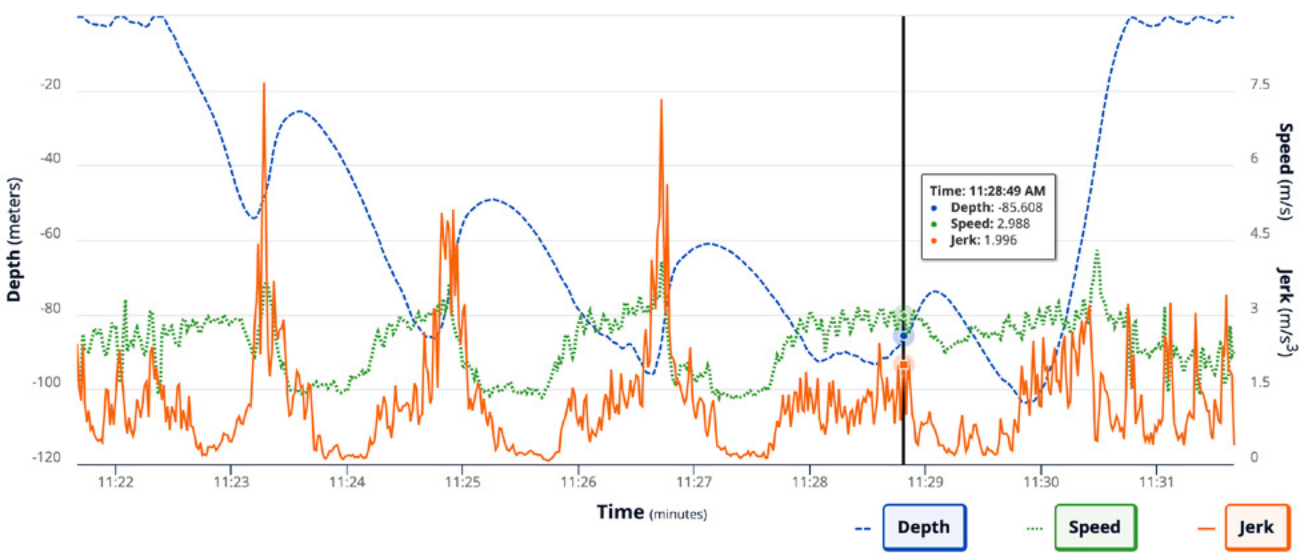

Figure 3. Data gathered from a tagged whale.

This graph (**Fig. 3**) shows data gathered from a tagged whale: a female that was first identified in 1994, making her at least 22 years old at the time the data were collected, and likely older. The x-axis represents time, while the y-axis has different meanings depending on which of three variables is being considered. Because the three lines share the same x-axis, the graph shows how these three characteristics of the whale's motion and position change together over time.

- The **dashed blue line** represents **depth**, which is measured by the tag's pressure sensor: the greater the water pressure, the greater the depth. Depth is given in meters.

- The **dotted green line** represents **speed**, measured in meters per second (m/s). The researchers can't measure speed directly underwater, because that would require knowing the whale's exact position, and as we saw in a case study (Week 2, Essay 1, "Little Robots That Go with the Flow"), GPS doesn't work underwater, so they use noise as a proxy. "Imagine sticking your head out the window of a car and the wind's rushing by you, and it gets louder as the car goes faster, and the dog's tongue is wagging a lot faster," says Cade. Similarly, the noise of the hydrophone (underwater microphone) and the shaking of the tag itself stand in for the whale's speed. Note the longish periods when the whale is maintaining a constant speed, which Cade calls gliding, punctuated by brief periods when it speeds up and slows down.

- The **solid orange line** represents **jerk**, which Cade describes as "a measure of how much that animal is moving around at different times." Technically, jerk is the rate of change of acceleration. It is given in meters per second cubed (m/s3). (For fans of calculus: Jerk is the first derivative of acceleration, the second derivative of speed, and the third derivative of position. The calculus-free version: Jerk is the rate of change of acceleration, acceleration is the rate of change of speed, and speed is the rate of change of position.)

Stop and Think

1. Review the single-dive data interactive. Can you spot the feeding behaviors that Dave Cade discussed?

2. Are there any new observations you were able to make? Describe them.