KEN MARTEN *Earthtrust*

Ring Bubbles of Dolphins

A number of bottlenose dolphins in Hawaii can create shimmering, stable rings and helices of air as part of play

by Ken Marten, Karim Shariff, Suchi Psarakos and Don J. White

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Below the towering cliffs of Makapuu Beach on the island of Oahu, Hawaii, is a unique laboratory dedicated to the study of dolphins. Project Delphis, run by the nonprofit conservation organization Earthtrust, in cooperation with Sea Life Park Hawaii, conducts research ranging from investigating dolphin self-awareness to exploring the animals' intelligence using an underwater computer touch screen. The scientists in the lab do not use food as a reward, so all the behavior observed is of the dolphins' own volition.

One of the most fascinating activities we have seen in our research involves no high-tech human toys at all. Instead the dolphins fashion their own entertainment by swirling the water with their fins and blowing bubbles into the resulting vortices to produce rings and helices of air. Furthermore, the physics behind the air rings turns out to be quite interesting. Few people doubt that dolphins are highly intelligent animals, but these observations demonstrate just how imaginative they can be.

As air breathers, dolphins blow bubbles whenever they exhale underwater. Dolphin behaviorists have noted that when dolphins are excited, surprised or curious, they will sometimes expel air from their blowholes, generating large, amorphous bubbles that rise quickly to the surface. The animals occasionally emit streams of small bubbles when they make sounds; the bubbles might add another component, detectable by sight or sonar, to the vocal message.

KAIKO'O (*left*), an adult bottlenose dolphin at Sea Life Park Hawaii, generates a rising ring of air to play with. The laboratory at the park (*above, right*) offers a window into the world of dolphins.

Dolphins can also create more exotic types of bubbles for less prosaic reasons. In recent years, researchers at several oceanariums around the world have reported that a variety of marine mammals can blow smooth, stable rings of air that linger in the water for several seconds. Because of the intricate techniques and practice required to form such rings, as well as the helices we have seen, these bubbles are clearly not a spontaneous response to alarm or a standard part of communication. Wolfgang Gewalt of the Duisburg Zoological Gardens in Germany observed untrained Amazon river dolphins (*Inia geoffrensis*) producing bubbles in unusual and playful ways. The animals emitted air from their mouths to yield necklaces of bubbles, which they would pass through or bite.

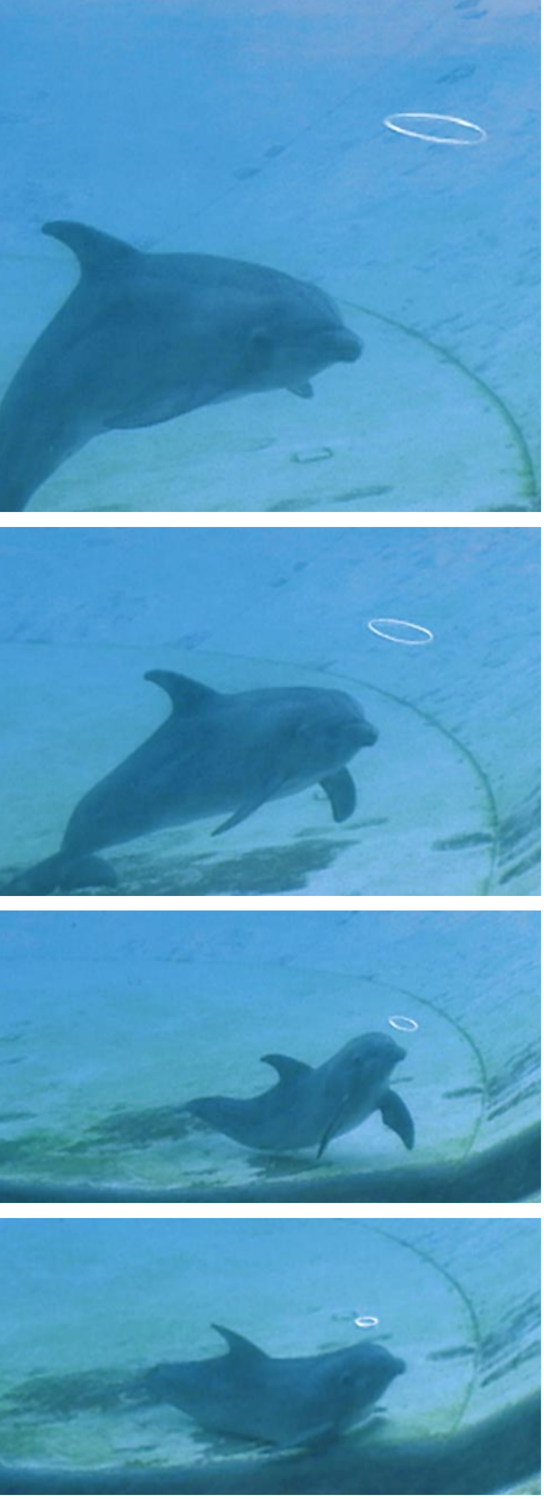
Elsewhere, at Marine World Africa USA in Vallejo, Calif., Diana Reiss and Jan Ostman-Lind noticed bottlenose dolphins (*Tursiops truncatus*) at the aquarium playing with rings similar to the ones we have seen. Kenneth S. Norris of the University of California at Santa Cruz described beluga whales (*Delphinapterus leucas*) at the Vancouver Aquarium that expelled bubbles from their blowholes and then sucked them into their mouths as part of playful behavior. Some people have even witnessed air rings in the wild. The behavioral biologist Karen Pryor observed male Pacific spotted dolphins (*Stenella attenuata*) blowing rings during social encounters; Denise Herzing of Florida Atlantic University has viewed similar displays in free-ranging Atlantic spotted dolphins (*Stenella frontalis*). And the marine mammal photographer Flip Nicklin has seen beluga whales living in Lancaster Sound in Baffin Bay, Canada, that released rings of air as they repeatedly clapped their jaws together, possibly in a display of aggression.

Hawaiian Ring Culture

During the past five years at Sea Life Park Hawaii, we have studied 17 bottlenose dolphins; nine of them, ranging in age from 1.5 to 30 years old, generated air rings. Based on our observations at other oceanariums and consultations with colleagues at various sites, we believe ring blowing is more common at Sea Life Park Hawaii than at other aquariums; the dolphins here appear to have created a "ring culture" in which novice dolphins learn to make rings in the presence of experts that, in a sense, pass down the tradition.

Ring making is a leisurely pastime, so the animals generate rings only when they want to—not on command or for a reward of food. Furthermore, ring making does not seem to be associated with functional behaviors such as eating or sexual activity. Because ring blowing is unpredictable, we have had some difficulty documenting it. But over time we have captured most of the dolphins at play in photographs and on videotape. (Additional photographs can be seen on the World Wide Web at http://earthtrust.org, and a Quicktime movie can be found at http://www.sciam.com/) Unfortunately, neither of these media does the dolphins justice. But the archived images do reveal important information about the physics of the rings.

From what we have seen, the dolphins employ three basic techniques to form the rings. In the simplest method (also



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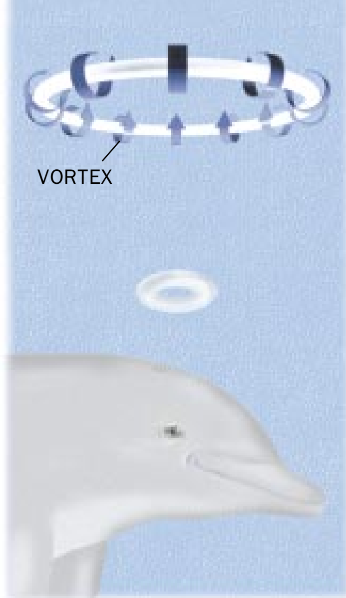

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HALO OF AIR becomes thinner and expands in radius as it is carried to the surface by the vortex flow (*arrows*) through the center of the ring. The vortex also serves to stabilize the ring, preventing it from breaking up into smaller bubbles. Here Kaiko'o produces a ring and follows it up through the water (*video stills, bottom to top*).

used by human divers), dolphins puff out bubbles from their blowholes; these bubbles become halos of air that expand in radius while decreasing in thickness as they rise to the surface [*see illustration above*]. One of the dolphins we watched, the adult male Kaiko'o, could emit two rings in succession and then fuse them into a single, large ring.

The physics behind this type of ring is relatively straightforward: any spherical bubble bigger than about two centimeters in diameter will quickly become a ring because of the difference in water pressure above and below the bubble. Water pressure increases with depth, so the bottom of the bubble experiences a higher pressure than the top does. The pressure from below overcomes the surface tension of the sphere, punching a hole in the center to create a doughnut shape.

As water rushes through this hole, a vortex forms around the bubble. Any vortex ring travels in the same direction as the flow through its center; in the case of these simple air rings, the vortex flow, in combination with the air's natural buoyancy, propels the bubbles toward the surface. Although the process of making air-filled rings is fairly simple, dolphins cannot blow stable ones without some practice, suggesting that additional factors—such as the viscosity of the water and how the air is ejected from the blowhole—need to be taken into account.

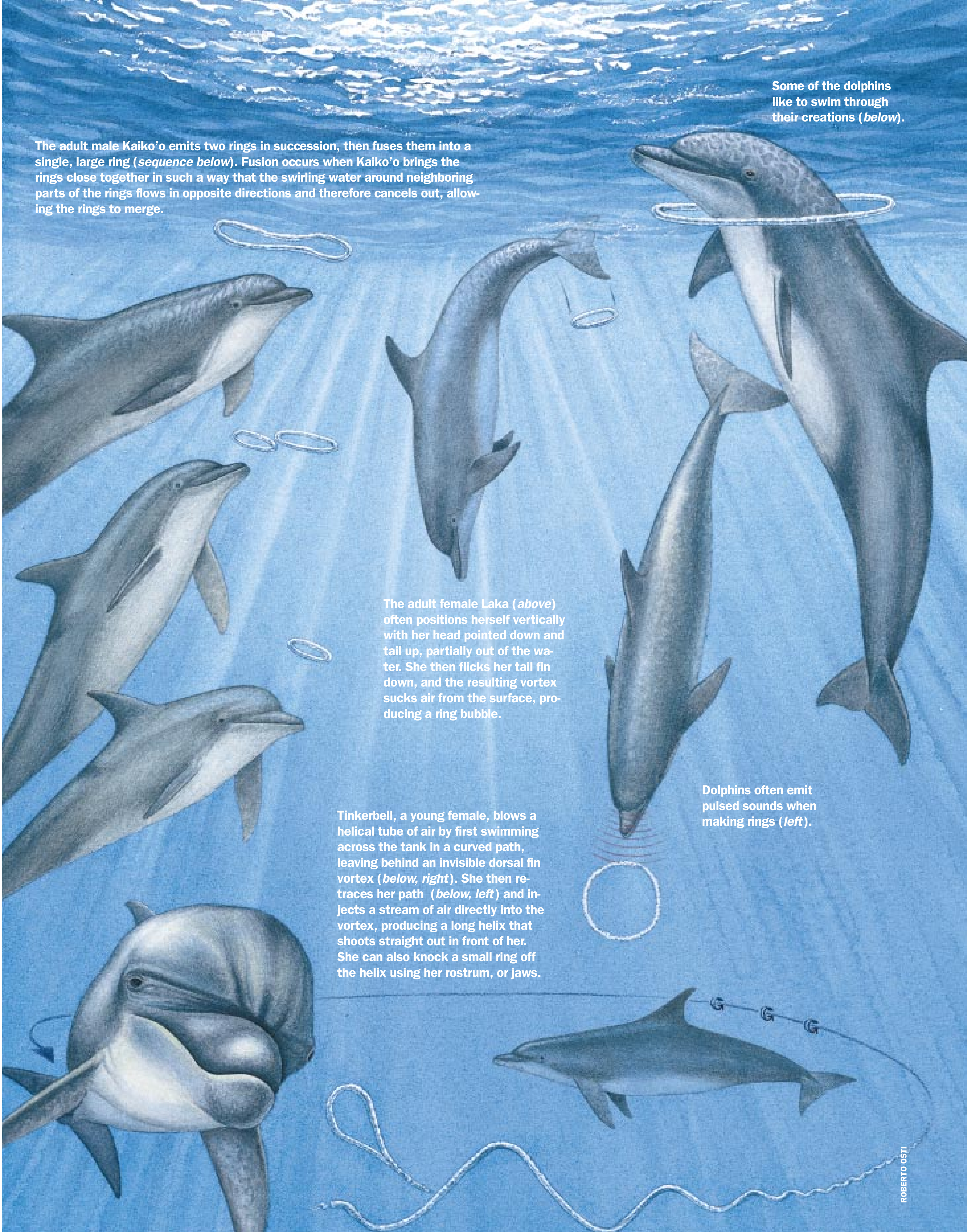
In a more elaborate approach, the dolphins fabricate rings that travel horizontally and sometimes even downward in the water. For instance, a dolphin might swim forward rapidly on its side so that its normally horizontal flukes (that is, its tail fin) are vertical. By thrusting its flukes vigorously to one side, the animal generates an invisible, ring-shaped vortex that travels horizontally and slightly downward. After quickly turning around, the dolphin finds the vortex and injects a bubble into it from the blowhole. (The dolphin often produces an audible series of clicks before the release of air, suggesting that sonar may be employed to locate the invisible vortex.) The pressure inside a vortex is lowest in the center, or "eye," of the swirl; when the dolphin exhales into the vortex, the air migrates to the region of lowest pressure and is drawn out along the core of the ring-shaped vortex [*see illustrations at top of pages 86 and 87*].

The resulting ring can be up to 60 centimeters (two feet) across and just over a centimeter thick, traveling horizontally in the water. Once again, the movement of the ring reflects the direction of the flow through its center; in the case of the vortex created by the dolphin tail fin, this flow is horizontal and sometimes even downward. With a sideways toss of its rostrum, or jaws, the dolphin can pull a small ring off the larger one and then steer it through the water.

Making a vortex with flukes and planting a bubble in it can be done in a variety of ways—the adult female Laka often positions herself vertically in the water with her head pointed down and tail up. Laka then flips her tail fin down to stir up a vortex. She fills the vortices not only with air from her blowhole but also with air from her mouth. Occasionally, Laka will capture air from above the water with a downward thrust of her flukes. In addition, we have watched Laka release from her mouth small bubbles that pass along her body; when the bubbles reach her flukes, she flips them into a ring. And she can even augment a ring by injecting more air into it.

Experimenting with Bubbles

The third type of air-filled vortex dramatically reveals the dolphins' capacity for experimentation. On a few occasions, we watched the young female dolphin Tinkerbell, Laka's daughter, construct long helices of air, using the most complicated technique we have seen. These more complex structures no doubt result from considerable refinement through trial and error. Tinkerbell has developed two very different methods for making helices. In one approach, she releases a group of small bubbles while swimming in a curved path near the wall of the tank. She then turns quickly, and as the dorsal fin on her back brushes past the bubbles, the vortex formed by the fin brings the bubbles together and coils them into a helix three


Some of the dolphins like to swim through their creations (*below*).
The adult male Kaiko'o emits two rings in succession, then fuses them into a single, large ring (*sequence below*). Fusion occurs when Kaiko'o brings the rings close together in such a way that the swirling water around neighboring parts of the rings flows in opposite directions and therefore cancels out, allowing the rings to merge.
The adult female Laka (*above*) often positions herself vertically with her head pointed down and tail up, partially out of the water. She then flicks her tail fin down, and the resulting vortex sucks air from the surface, producing a ring bubble.
Dolphins often emit pulsed sounds when making rings (*left*).
Tinkerbell, a young female, blows a helical tube of air by first swimming across the tank in a curved path, leaving behind an invisible dorsal fin vortex (*below, right*). She then retraces her path (*below, left*) and injects a stream of air directly into the vortex, producing a long helix that shoots straight out in front of her. She can also knock a small ring off the helix using her rostrum, or jaws.
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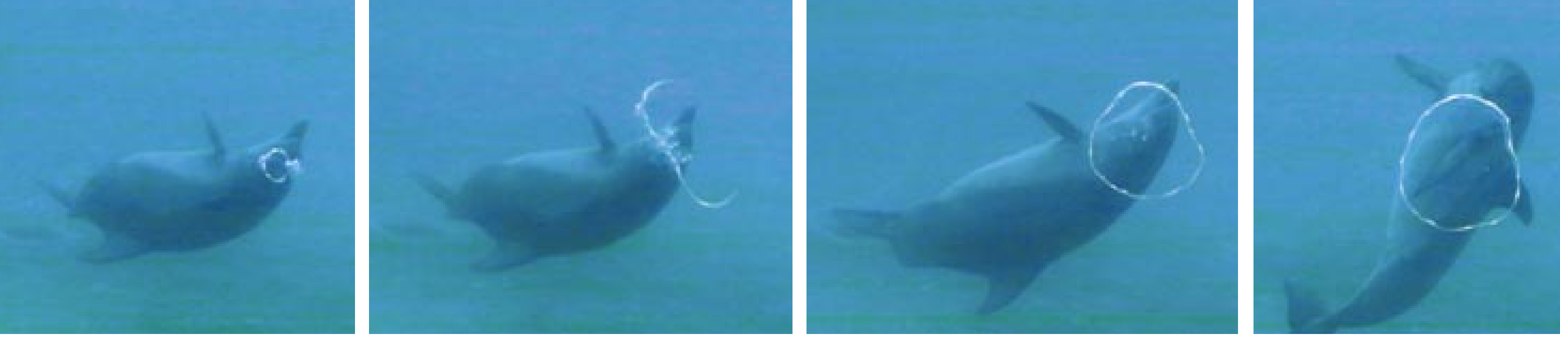

to five meters (10 to 15 feet) long [*see illustrations at bottom of these two pages*]. We have also seen Tinkerbell swim across the tank in a slightly curved path, leaving behind an invisible dorsal fin vortex. She then retraces the path and injects a stream of air into the vortex, producing a long helix that shoots out in front of her.

Again, because the pressure in a vortex is lowest in the eye, once the bubbles are inside the vortex, they move toward the center, merge and elongate into a helical tube. Usually a tube of air in water is unstable and breaks up into smaller bubbles. But all the dolphins' rings and helices are shiny and smooth because the variation of pressure inside the vortex (low pressure at the center, building up to higher pressure at the edges) actually works to stabilize the tube by smoothing the ripples that would otherwise break up the large bubble.

Although we did not see any dolphins other than Tinkerbell generating helices, the practice of making rings spread through the population of dolphins, as some of the individuals learned the technique in the presence of their ring-blowing companions. We had the opportunity to watch one young dolphin's rings evolve over a period of two months from unstable, sloppy bubbles that dissipated rapidly to stable, shimmering rings that lingered in the water for several seconds. Older dolphins also needed time to acquire the talent. One adult male, Keola, lived in the research tank for two years with dolphins that did not produce air rings, and during that time we did not see him generate any. But when his younger, ring-blowing sibling Kaiko'o moved into the same tank, Keola watched for long stretches while Kaiko'o blew rings; within a couple of months, Keola began making his own rings, which slowly progressed in quality.

We have noticed that other dolphins also monitor their ring-blowing tank mates intently, suggesting that the exhibition interests the animals or offers a learning opportunity for them. On several occasions we saw the two brothers Keola and Kaiko'o lying side by side on the bottom of the tank, repeatedly blowing large doughnut rings either simultaneously or within a second of each other. We have also seen one female, swimming closely behind another female who was blowing rings, produce her own bursts of small bubbles as she watched.

The dolphins have drawn humans into their play as well: one day during a period of intense ring making, Tinkerbell repeatedly blew a ring and then came to the lab window where one of us (Psarakos) was videotaping, as if to include her in the activity. Once, we blew soap bubbles inside the lab in front of the dolphins' window, and within a few minutes one of the dolphins joined in by blowing simple, rising doughnut rings

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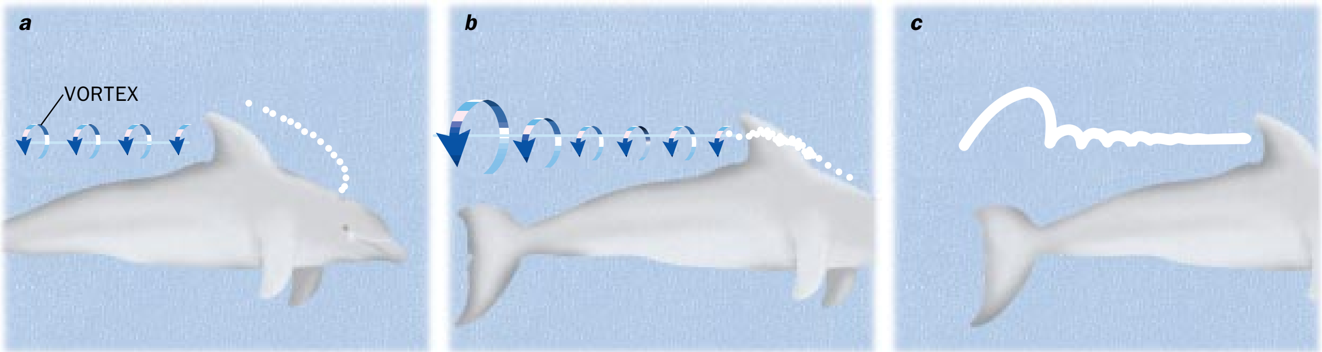

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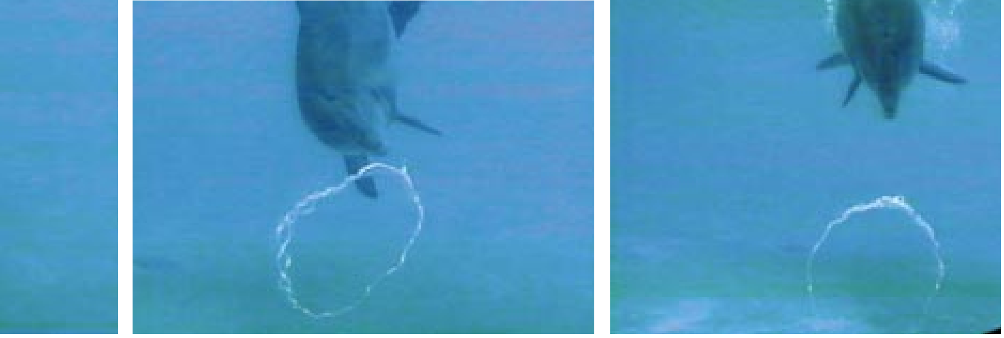
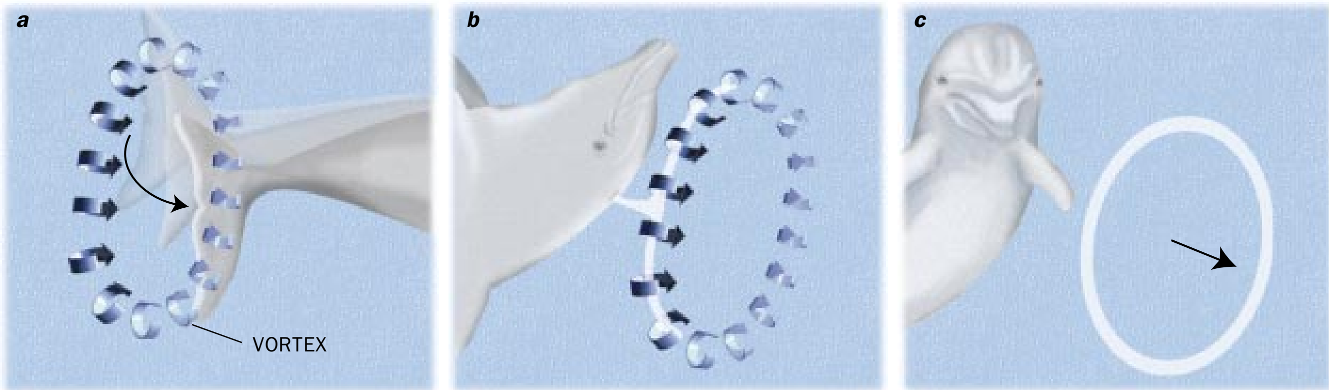
CORKSCREWS OF AIR are uncommon: the authors have observed only Tinkerbell (*video stills, above*) create them. In one technique, Tinkerbell emits a burst of bubbles while producing a spiral vortex off the dorsal fin (*a*). When the bubbles encounter the vortex (*b*), they are drawn into it, then merge and elongate into a long helix of air (*c*).



HORIZONTALLY MOVING RING forms when a dolphin flicks its tail while swimming on its side. The horizontal and slightly downward motion of the fin creates a vortex traveling in the same direction (*a*). The dolphin then turns around and injects air into the swirling flow (*b*); the air is drawn along the core of the vortex (*c*), forming a ring that moves in the direction of flow through its center. The adult female Laka is pictured (*left*) exhaling into the vortex and examining her creation.



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near the lab window. The real surprise came when the dolphin swam away from the window and made several fluke vortex rings—so different from what we each blew at the window.

Our study of the bottlenose dolphins at Sea Life Park Hawaii continues in the hope of better understanding their behavior. As the only nonprimates that have shown strong indications of self-awareness, these dolphins may teach us about the nature of intelligence through their experimentation and play. But as we consider their remarkable abilities, we are haunted by the knowledge that many cultures, including our own, regard dolphins as expendable. Dolphins continue to be targeted by tuna nets, to become ensnared in expansive drift nets and gill nets, to be canned as mock whale meat and to be shot for crab bait or to be hunted for sport. Earthtrust and its sponsors work to address these issues, but we believe only a basic change in human behavior will make a permanent difference. It is our fervent hope that by providing new views into the dolphin mind, we may yet convince people to stop the indiscriminate slaughter of these fascinating creatures. SA

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Information on Earthtrust is available from earthtrust@aloha.net or 25 Kaneohe Bay Drive, Kailua, HI 96734.

Further Reading

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USING SELF-VIEW TELEVISION TO DISTINGUISH BETWEEN SELF-EXAMINATION AND SOCIAL BEHAVIOR IN THE BOTTLENOSE DOLPHIN (*TURSIOPS TRUNCATUS*), by Ken Marten and Suchi Psarakos, pages 205–224, and related articles on animal consciousness in *Consciousness and Cognition,* Vol. 4, No. 2, pages 205–269; June 1995.

General information on dolphin cognition research and the organization Earthtrust is available on the World Wide Web at http://earthtrust.org