Marine mammals

Major Groups of Marine Mammals

1. Pinnipedia – seals, sea lions and walrus
2. Carnivora – sea otter and polar bear
3. Sirenia – dugong and manatees
4. Cetacea – whales, dolphins and porpoises

2

Order Cetacea

- This order includes whales, dolphins and porpoises.
- Fore limbs are modified into flippers.
- Fin-like tail is known as a fluke.
- Nostrils are located on the top of the head as a single or double opening known as a blowhole.

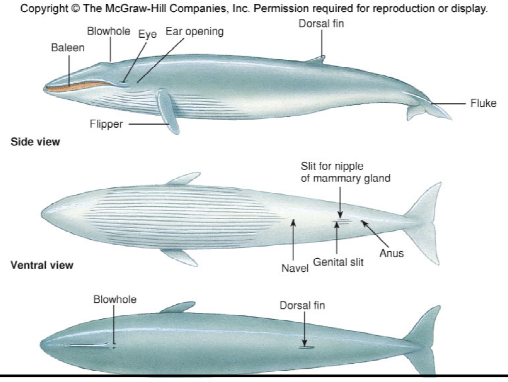
3

Order Cetacea

- Within the cetacea, two suborders exist, toothed whales (Odontocetes) and baleen whales (Mysticetes).
- Visually, the two suborders can be easily distinguished by the presence of teeth and a single blowhole (Odontocetes) or baleen and two blowholes.
- **SIZE:** In general, baleen whales are much larger than toothed whales, ranging in length from about 6.4-27 m (21-85 ft.). Most toothed whales are less than 6.1 m (20 ft.) long.

4

Baleen whales have rows of flexible, fibrous plates known as baleen that hang from the upper jaws (seen in diagram below).



5

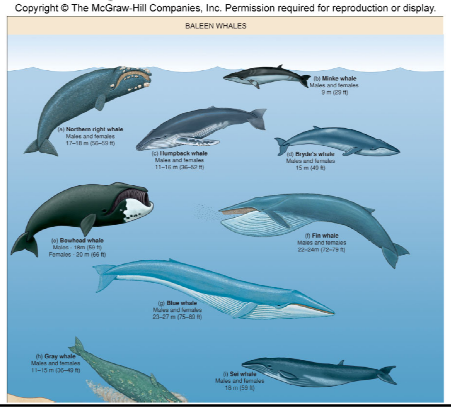
Blue whale feeding

Order Cetacea

- Baleen whales are filter feeders. They take in huge mouthfuls of water containing small fishes or invertebrates. The baleen traps the prey, and water is forced back out of the mouth.
- Baleen whales are represented by 13 species, including the right whale, gray whale, blue whale, and humpback whale.

7

Examples of Baleen Whales



8

Order Cetacea

- Toothed whales are named for their simple, peg-like teeth, which vary considerably in number and size among the species.

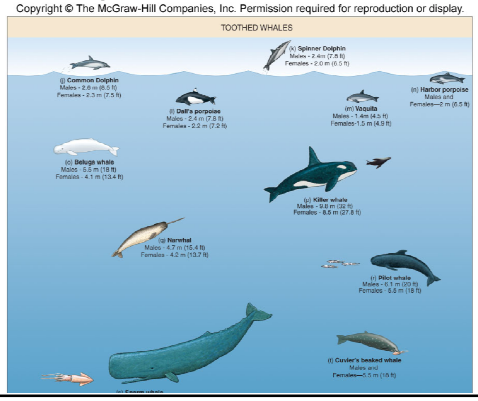
9

Order Cetacea

- Toothed whales include dolphins, porpoises, belugas, narwhals, sperm whales, killer whales, river dolphins, and beaked whales.
- Depending on the species, toothed whales may be found in coastal waters, rivers or in the pelagic environment.

10

Examples of Toothed Whales



11

Captive orca

- 2010 large male, 22 foot 12000 pound kills trainer at seaworld.
- Involved in 1-2 other deaths
- Trainers were apparently not supposed to go into water with the orca
- Orca may have been “playing” with trainers ponytail
- This male is used for breeding purposes and has fathered about 15 calves at Seaworld

In defense of captive orcas

- Former SeaWorld head trainer Thad Lacinak says captive killer whales serve as ambassadors of the species to educate the public and help protect them in the wild. "These animals are invaluable in terms of what we can learn from them. And you cannot learn about killer whales through a pair of binoculars.“
- Gary Wilson, a professor at Moorpark College in California, "If it was a perfect world we wouldn't need to have any animals in captivity, but the reality is in order to learn about these animals and to actually ensure their survival in the wild, we need to have them in captivity so we can study them and people can learn to appreciate them," Wilson said. "If SeaWorld didn't have dolphins and whales in captivity, there would be many fewer people in the world that even cared about them at all.“
- Even in captivity, orcas rarely attack out of aggression, Lacinak said, adding that they are usually cases of a killer whale trying to play with a trainer. The whale likely saw the trainer's ponytail as a toy, then dragged the woman into the water and turned it into a game.

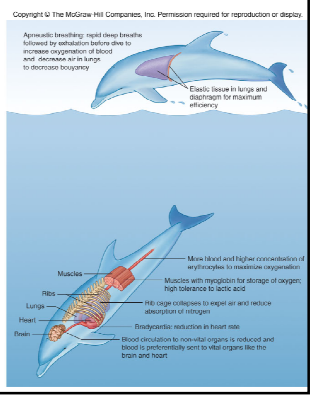
In opposition to captive orcas

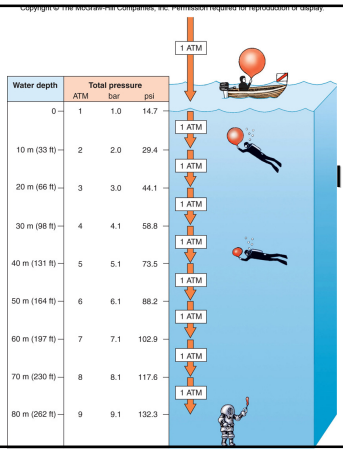
- "Orcas are simply too big, too complex, too intelligent to be adequately accommodated in captivity," said Naomi Rose, a marine mammal scientist with the Humane Society of the United States. "The tanks are always going to be too featureless, too small. ... The number of incidents where trainers have been injured is much greater than most people know. They aren't all reported.“
- Orcas in the wild can travel up to 100 miles in a day and thousands of miles in a lifetime in the ocean, where they are generally harmless to humans, said Howard Garrett, co-founder and director of the Washington-based nonprofit Orca Network.
- "Humans trying to incarcerate orcas or elephants or any type of large brain or large society species, it's proven it doesn't work," said Mark Berman, associate director at the environmental group Earth Island Institute in Berkeley, Calif. "They're just too big." “No animals were meant to entertain humans.”

Diving

Adaptations for Diving:

- Rapid breathing prior to dive -known as apneustic breathing
- Lungs remove 90% of O_2 from air (as opposed to 20% for humans)
- Elastic tissue in lungs helps them expand the lungs temporarily during apneustic breathing
- Marine mammals have more blood than non-diving mammals for their size (means more hemoglobin to carry oxygen)
- Muscles contain more myoglobin to hold oxygen in tissues
- The heart rate slows dramatically during a dive – known as bradycardia
- Blood flow is reduced to extremities and digestive system
- Muscles employ anaerobic respiration as necessary (results in lactic acid build-up)
- Marine mammals can tolerate more lactic acid than other mammals
- Rib cage and lungs collapse during dive to force air into tissues and prevent decompression sickness





Pressure Increases with Increasing Depth

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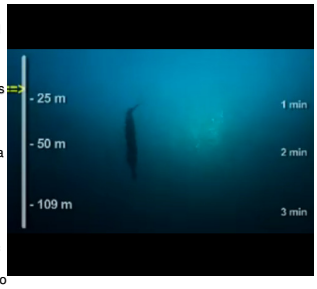


Human freedive

- Blue hole Red Sea http://www.youtube.com/watch?v=hrXQbucZUDA
- World record free dive
- http://www.youtube.com/watch?v=e_Ojj2XxyMo

Some animals just go anaerobic for extended periods of time

Turtles and lungfishes rely on liver glycogen during submergence

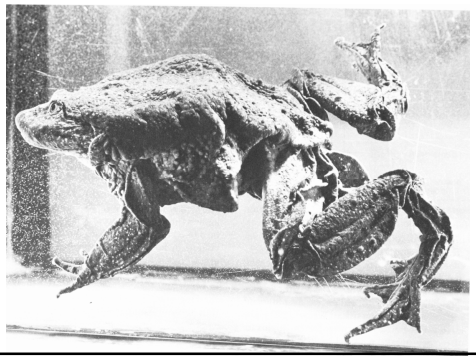
- After maximal submergence liver glycogen not fully depleted
  - *Additional glycogen stores in other tissues
  - More efficient fermentation pathways
  - *Reduced metabolic rates

Metabolic depression extends turtle anoxia tolerance

- Liver glycogen 880 umols/g
- 100 g turtle 8.6 g liver =7600 umols glycogen glucose
- 2.9 days of ATP
- Kept in laboratory at 3 C in anoxic water for 6 months

Some animals learn to breathe through their skin

Some divers breathe through their skin
Lake Titicaca frog http://www.youtube.com/watch?v=j06d2CjoIcI



- hellbender (*Cryptobranchus alleganiensis*) are extremely large, completely aquatic salamanders native to the eastern United States. The largest hellbender ever recorded was nearly 2 1/2 ft. long

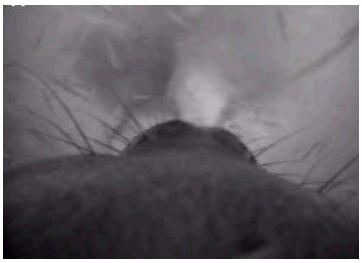
http://www.hellbenders.org/hellbendervideo.html

http://www.youtube.com/watch?v=6

Mammalian divers

- **Weddell Seal, Location: Antarctic circumpolar**
- **Up to 10 ft long 1000 pounds**
- **can dive over 2000 feet deep and stay submerged for 1.2 hours**

- **The view from the top of the head of a diving Weddell seal as it blows bubbles into the under ice surface. We discover that sometimes the bubbles are used to scare "borks" out of the ice for the seals to eat. Other times the bubbles are used to scare off other seals that try to steal breathing holes. (VDAP video image)**



Weddell seal diving

- http://www.youtube.com/watch?v=S_6bhnnC9pM
- http://www.youtube.com/watch?v=rKJCiZ5YPxg
- http://www.youtube.com/watch?v=opOUh0xRQ9Q

Weddell seal: keeping the brain alive during long dives

Brain energy requirements during diving

	Diving seal 450 kg	Resting human 70kg
Brain kg	0.5	1.4
Brain % body wt	0.1%	2%
Brain O2 cons/1.2 h	48 mmoles	151 mmoles
Whole organism O2 cons/1.2 h	5,697 mmoles	960 mmoles
Brain O2 cons % of total	0.8%	15%

Brain blood glucose utilization

	Seal 60L blood	Human 5.6 L blood
Total blood glucose pool	300 mmoles	28 mmoles
Brain uptake/1.2 h	10.8 mmoles	25.2 mmoles
Brain % total glucose used	3.6%	90%

Metabolism of three main organs is only a small portion of whole met rate

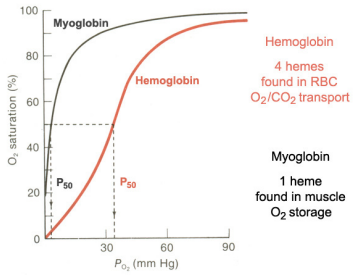
- 1000 mmoles blood O2; 500 mmoles myoglobin O2
- 1.2h dive
  - Brain 3-4%
  - Heart 15-20%
  - Lung 7%

A closer look at traits associated with diving performance

- Swimming styles - gliding
- Expanded blood volume, RBC mass, or hematocrit- Use of the spleen for RBC storage
- High muscle Mb
- Diving responses
  - Apnea
  - Bradycardia
  - Peripheral vasoconstriction
  - Low lactate accumulation
  - Postdiving lactate washout within 1-4 minutes of recovery

High muscle myoglobin

- Stores oxygen in muscle tissue



Hemoglobin

4 hemes found in RBC O_2/CO_2 transport

Myoglobin

1 heme found in muscle O_2 storage

Minke whale meat $80/kg

Sink or Swim: Strategies for Cost-Efficient Diving by Marine Mammals
Terrie M. Williams, *et al.*
Science **288**, 133 (2000);

Black = stroking
Red= gliding

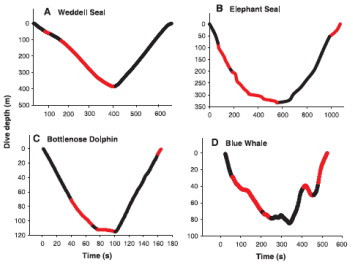


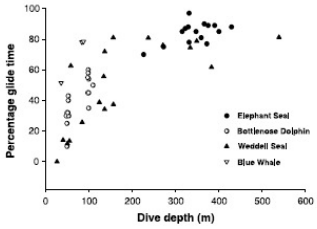
Fig. 1. Locomotor activity of four species of diving marine mammal. Representative deep dives are presented for the (A) Weddell seal (maximum depth = 385 m), (B) northern elephant seal (333 m), (C) bottlenose dolphin (115 m), and (D) blue whale (84 m). Each curve represents dive depth in relation to time elapsed during the dive. Color of the line corresponds to stroking (black) and gliding (red) periods. Stroking periods include both continuous stroking and stroke-and-glide activities. Note the prolonged gliding period during descent for each species.

%glide time increases with dive depth

Fig. 2. Percentage glide time during descent in relation to dive depth for four species of marine mammal. Each point represents an individual dive. The data were described by the nonlinear function, percentage glide time =

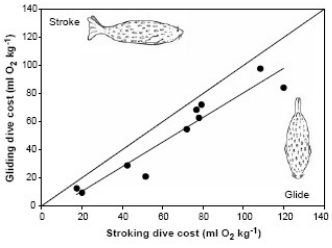
$$85.9 - \left(\frac{2820.3}{\text{Depth}}\right)$$

($n = 53$, $r^2 = 0.70$, $P < 0.001$). Except for the dolphins, the range of depths was determined by the free-ranging behavior of the instrumented animals.



Gliding dive costs are lower than stroking dives

Fig. 3. Recovery oxygen consumption of gliding dives in relation to stroking dives for free-ranging Weddell seals (34). Each point represents a gliding dive paired with a stroking dive of equal distance traveled (±60 m) for an individual seal. Total distance traveled ranged from 354 to 3614 m, which resulted in the range of energetic costs. The thin line through the origin represents the line of equality for the cost of gliding dives and stroking dives. The thick solid line denotes the least-squares linear regression through the data points. Dives incorporating prolonged gliding were consistently less costly than stroking dives of similar distance, as described by glide cost = 0.88 stroke cost − 7.30 ($n = 10$, $r^2 = 0.91$, $P < 0.001$). Consequently, all paired dives fell below the line of equality.



- Spleen empties rbc content in first minutes of dive into hepatic sinus then rbcs metered slowly into circulation

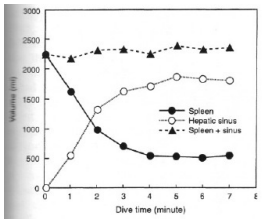
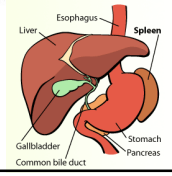


Figure 4.3. Representative set of spleen and hepatic sinus volumes, measured in vivo with MRI, during an 8 min simulated dive in a young elephant seal. The MRI images indicated that spleen emptying requires only two or so minutes. The contents are initially tranferred into the hepatic sinus and then RBCs are metered out into the blood more slowly, apparently through phrenic nerve control of the caval sphincter. Data from Thornton (2000).



Bradycardia: Evolution of diving response

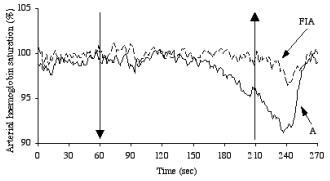
- Suppression of heart rate to as low as 4 bpm is conserved in pinnipeds even those that do not make extreme dives
- Bradycardia is conserved in mammals
  - Hibernating bears exhibit similar bradycardia and hypoperfusion (share common ancestry with pinnipeds)
  - Human bradycardia down to 6 bpm

Cardiovascular characteristics of Weddel Seals

- Weddell seal
  - 60 → 15 beats/min
  - Cardiac output 40 → 6 L/min
  - Blood pressure maintained at 120 mm Hg
  - Blood flow – CNS unchanged; organs/tissues 1/6 to 1/20 normal

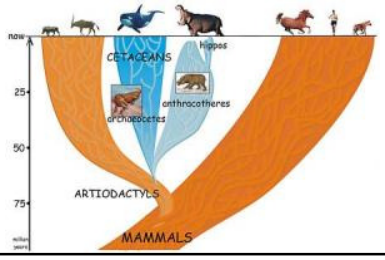
Mammalian dive response

- Response of face submersion in water
- Strong in aquatic mammals, but also in humans. Present in diving birds
  - Bradycardia
  - peripheral vasoconstriction
  - Triggered by cold sensitive nerves in nasal area



Evolution of cetaceans

- Closest living group: Hippos
- Were land animals that moved back to the water



Pakicetus

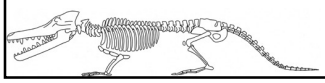
- About 60 years ago, researchers first suggested that cetaceans were related to plant-eating ungulates, specifically to even-toed, artiodactyl mammals like sheep, antelope and pigs.
- Traditionally, the origin of whales was linked to the mesonychids, an extinct group of carnivores that had singly-hoofed toes. Pakicetus, dog like with hooved feet, and triangular teeth like early whales
- 2009 phylogenetic analysis with DNA sequence data as well as morphological and behavioral characteristics suggest that this is not the ancestor of whales

Indohyus - 4 legged ancestor of whales

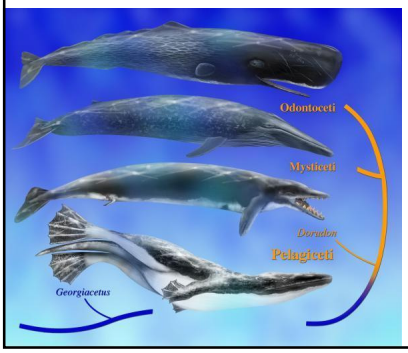
- The 48 million year old ungulate Indohyus from India. Indohyus is a close relative of whales, and the structure of its bones and chemistry of its teeth indicate that it spent much time in water. In this reconstruction, it is seen diving in a stream
- key similarities between whales and Indohyus in the skull and ear adapted for hearing underwater
- Indohyus was a plant eater
- http://www.youtube.com/

Ambulocetus – “walking swimming” whale

- Ambulocetids are large, powerful animals, with short limbs, but big feet, and a strong tail.
- only found in northern Pakistan and western India in rocks that indicate that the environment was nearshore marine and swampy.
- rocks cannot be dated with great accuracy, but they are clearly younger than the sediments in which pakicetids are found. Although ambulocetids could walk on land as well as swim, it is clear that they were not fast on either terrain.



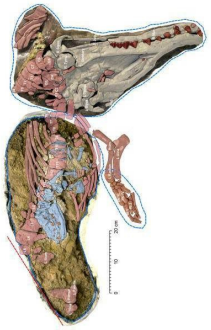
Evolution of the tail fluke - *Georgiacetus vogtlensis*



- previously unknown bones from the tail show that it lacked a tail fluke.
- it did have large back feet that it may have used as hydrofoils
- Undulating the body in the hip region was the key factor in the evolution of swimming.

Early whales probably came on land to rest and reproduce

- 47.5 million yr old extinct whale in the group known as Archaeoceti
- Fossils of female Maiacetus inuus with near-term fetus in utero, as found in the field. The female's skull is shaded white (teeth brown), and other parts of her skeleton are shaded red. The single fetus, in birth position inside the mother whale, is shaded blue (teeth orange).
- The fetus is positioned for head-first delivery, like land mammals but unlike modern whales, indicating that these whales still gave birth on land.



Why tail first?

- In a complicated birth, blowhole is last to emerge, preventing inhalation of seawater

Cetacean intelligence

- Large brain size
- Complex sound production
  - Extensively study but does not appear to be language
- Behavior
- http://www.youtube.com/watch?v=TMCf7SNUb-Q

Total brain weight

Table 1. Approximate brain weights and body weights of some mammals, in order of brain weight.

Species	Brain Weight (approx.) grams	Body Weight (approx.) tonnes
sperm whale (male)	7,820	37.00
African elephant	7,500	5.00
fin whale	6,930	90.00
killer whale	5,620	6.00
bottlenose dolphin	1,600	0.17
human	1,500	0.07
cow	500	0.6

Relative brain weight

Table 2. Approximate brain weights as a percentage of approximate body weights of some mammals.

Species	Brain Weight as % of Body Weight
human	2.10
bottlenose dolphin	0.94
African elephant	0.15
killer whale	0.09
cow	0.08
sperm whale (male)	0.02
fin whale	0.01

Brain size confounding factors

- Relation to body size
- Effect of brain size within a single species
- Which part of the brain (quality vs. quantity)

Brain neocortex (greatly developed in primates and humans)

- spiny anteater (an egg laying mammal, related to the duck-billed platypus), neocortex (relatively much larger than that of a human.
- bottlenose dolphins have a much higher index of neocortex folding than humans. However, neocortex of the cetacean brain is relatively thin - about half that of humans - giving a total average dolphin neocortical volume about 80% of that of humans.
- REM sleep → brain repair; spiny anteaters and dolphins are the only mammals tested that don't have REM sleep

learning

Table 3. Learning set formation (data from various sources cited by Macphail,1982)

Species	Score % (trial2)	Encephalization Quotient (EQ)	Order
langur	98	1.29	primate
mink	95	? (1-1.5)*	carnivore
ferret	90	? (1-1.5)*	carnivore
bottlenose dolphin	87	5.31	cetacean
rhesus monkey	86	2.09	primate
cat	70	1.71	carnivore
rat	60	0.40	rodent
squirrel	60	1.10	rodent

* exact EQ not available, and these species have been given the general carnivore EQ range

Mirror self recognition

- humans and great apes show mirror self recognition

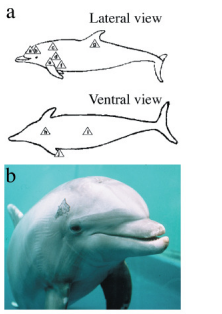
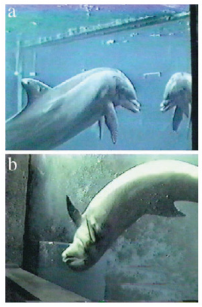


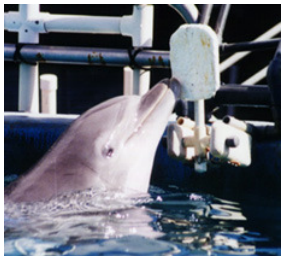
Fig. 2. (*A*) Locations of the nontoxic, temporary mark and the number of times the dolphins were marked in each location in mark and sham-mark sessions. Marks were applied to either side of the body. Subject 1: b, above eye (right, $n = 1$); c, above and posterior to ear (right, $n = 3$; left, $n = 4$); d, between ear and pectoral fin (right, $n = 2$; left, $n = 2$); e, above pectoral fin (right, $n = 2$; left, $n = 1$); f, posterior to pectoral fin (left, $n = 1$); g, below dorsal fin (right, $n = 2$; left, $n = 7$); h, between pectoral fin ($n = 2$); i, umbilical ($n = 1$); j, underside and tip of pectoral fin (right, $n = 1$). Subject 2: a, on melon (right, $n = 1$; left, $n = 2$); e, above pectoral fin (right, $n = 5$; left, $n = 2$); g, below dorsal fin (right, $n = 2$; left, $n = 1$; umbilical, $n = 2$); h, between pectoral fin ($n = 1$). (*B*) The dolphin marked above the right eye.



ig. 4. (A) Mark-directed behavior by subject to a real mirror immediately fter release from being marked. A narrow Plexiglas mirror, 41.9 cm × 101.6 m × 0.32 cm is affixed in a vertical orientation to the exterior of one of the eflective walls (Wall 6). During this session, the mirror was the best reflective urface in the subject's environment. The faint white line on the wall indicates he location of mirror. (B) The dolphin at Wall 1, the best reflective surface in he session, exhibiting late sham-directed behavior: a continuous and repet- tive sequence of 12 dorsal-to-lateral-ventral flips exposing the location of the ham-marked area of his body, the underside and tip of the right pectoral fin, to he reflective surface. This unusual behavioral sequence continued for 32 sec.

Akeakamai

- Yes no answer to symbolic references to objects that were or were not present



TV watching

- chimpanzees show at most a fleeting interest in television
- language -trained chimpanzee subjects, only learned to attend to and interpret television scenes after months of exposure in the presence of human companions who reacted to the scenes by exclaiming or vocalizing at appropriate times
- image of the trainer on the screen. The trainer then proceeded to give Akeakamai instructions through the familiar gestural language. The dolphin watched and then turned and carried out the first instruction correctly and also responded correctly to 11 of 13 additional gestural instructions