Cetaceans ECHOLOCATION and whales SOUNDS comparison

55 50 45 40 35 30 25 Millions of years ago

Kingdom: Animalia
Phylum: Chordata
Class: Mammalia
Order: Cetacea

1. ORIGEN and EVOLUTION of cetaceans

Cetaceans are a monophyletic order that consist of two suborders which evolved from Artiodactyla (even-toed ungulates) about 52 million years ago; these are Mysticetes and Odontocetes, which are fully aquatic. They share the majority of mammals traits e.g., pulmonary breathing, endothermic animals and nursing young.

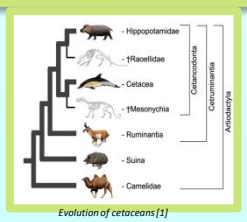
Adaptation to an aquatic lifestyle though, lead to few changes such as their modified fore limbs into flippers and vestigial hind limbs and underwater vision and hearing. Despite of the main characteristics due to this new environment, cetaceans possess large brains and some of them a high encephalization level, which are involved in echolocation.
Likewise, neither high encephalization level nor aquatic lifestyle are considerate the reason for owning this convoluted system.

Characteristics of ODONTOCETS

Nearly 90% are toothed whales, the presence of teeth defines this group, and their sizes vary among the species being smaller than mysticetes. They have a single blowhole and can dive and hunt in social ties or individually depending on the diverse species as well. They silent feature is the use of echolocation to locate prey and navigate, and their highly developed encephalization level.

characteristics of MYSTICETES

They are also called baleen whales for having baleen plates, rather than teeth used for filtering krill. These are a type of stiff hair made of keratin than hang from the upper jaw. They have two blowholes. Larger than toothed whales, are organized in small social pods or solitary. Mysticets produce infrasonic signals used in communication or navigation, usually long and low-frequency sounds (<20Hz) that can be heard many kilometres far away.



Evolution of cetaceans [1]

2. AUDITORY System

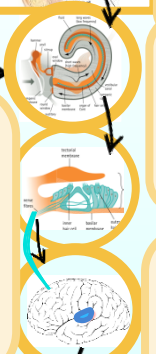
Mammal's ear is composed by an external ear, an ear middle ear, and a liquid-filled inner ear.

1.The **OUTTER EAR** is formed by the pinna which captures the sound that goes through the external auditory canal, and finally goes through the tympanic membrane.

2.The vibrations of the sound follow the ossicles (**MIDDLE EAR**) until reaching the oval window which produce fluid movements.

3.1 Finally, in the **INNER EAR**, passing through the vestibular organs, there is the cochlea (coiled tube filled with fluid) divided in 3 chambers. The responsible to drive the information to the brain via the auditory nerve are locate in the **Organ of Corti** within the Scala Media middle chamber border to the lower one (Scala Tympani) with the basilar membrane.

This structure varies in thickness along its length correlated with the different frequencies encoded. The fluid movements created in the cochlea made the basilar membrane vibrate as well, thus hair cells are displaced and their membrane potential despolarizes or hyperpolarizes making contact with neurons.



The information from the Organ of Corti goes through spiral ganglion cells through the ventral cochlear nucleus, neurons synapse in the Superior Olivary Nucleus and the output information travels in the lateral meniscus to the inferior colliculus (process auditory signals) and following there is the Medial Geniculate body (thalamus) and finally the information reach the auditory cortex in the superior temporal gyrus.

Cetaceans possess the same structures but enlarged, and some of them are even more in river dolphins. Likewise, echolocators have these hypertrophies due to processing convoluted echolocation signals. The most salient feature is the location of the auditory cortex different from mammals.

1.CETACEANS lack of a pinna, and their external auditory canals have been reduced into a narrow channel their canals end in a blind bag, hence there is no connection between outer and middle ear.

2. Instead of the eardrum, cetaceans have a strip of hyaline membrane, following the osscicles are enlarged and dense.

The **Tympano-periotic complex** (TPC) bone located in the peribullar cavity, that it consist of a periotic bulla (houses the inner ear) partly fused with a tympanic bulla (encloses the middle ear). They also possess an extensive innervation by a large number of trigeminal fiber nerves.

3. Is particularly small and there's been a reduction of the vestibular innervation. The cochlea had evolved; all her duct structures are hypertrophied, but in mysticete's are less endowed.
They have higher-frequency sensitivity due to a thick and width basilar membrane.
Animals with ultrasonic hearing have ossified the outer spiral laminae, and animals with low frequency have this structure reduced. In mysticetes, their laminae are spongy and fragile.
Depending of the ear formats and width frequency, cetaceans can be organized in three groups (type I, type II, and type M).

Baleen ears are not completely separate from the skull; its periotic bone is bounded to it. Mysticetes have an open cavity considerably larger with massive ossicles loosely joined (low frequency configuration)[2].

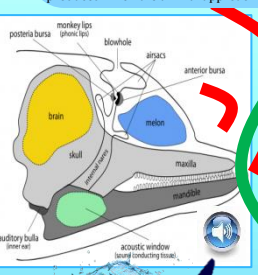
Odontocetes have no osseous connection between the TPC and the rest of the skull; it is just suspended by ligaments. There is a spongy tissue filled with air spaces around. It provides acoustic insulation from the rest of the cranium. Echolocating species have their middle ear cavity aligned with two fatty channels, that function as a low frequency conduit. Odontocetes have middle ear structures more rigid and is tuned to high frequencies [2].

3. Sound PRODUCTION

3.1 ECHOLOCATION

These animals use echolocation to gather information from the environment in order to know what they have around.
They don't possess vocal cords, on the contrary there is a complex tissue called the **DORSAL BURSA** that includes the phonic lips (two) which project into the **NASAL PASSAGE**. When the air pushes through it, the tissue around vibrates producing sounds. They are also produce by air movements in the nasal passage and through three types of **AIR SACS** [3]located outside the skull.

Both phonic lips can execute independently and simultaneously producing whistles and clicks. The animal develops its own signature **WHISTLE**, and is able to learn and recognise these sounds, in contrast, **CLICKS** are the type of sounds used during the dives while hunting a prey. The production of one click closer to another one is produced when the animal approach their prey.



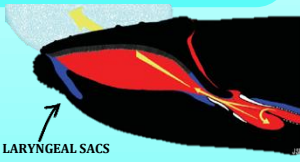
The animal also use the nasal passage to make a sequence and send it through a fat filled area in the forehead called **MELON**, which acts as an acoustical lens to focus the sound waves into a beam.

When the sound bounces off objects it return back to the animal and is received through its fat-filled cavities (multiple lobs) called **ACOUSTIC WINDOW** located in the lower jaw bone, and a thin bony called the **PAN BONE**. Both structures conduct sound to the middle ear.

3.2 Whale Sounds

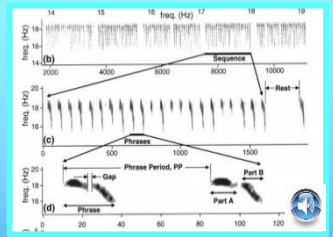
Mysticetes produce sounds with their enormous larynx, rather than phonic lips because baleen whales lack of them, just as they didn't have vocal cords. They possess enlarged **LARYNGEAL SACS** [4], located in both sides of the glottis, and are fused along the ventral middle of the throat. The sac enables air to be recycled between the larynx and lungs during vocalization and works as a resonating chamber when is inflated, therefore this structure is involved in vocalising their famous songs. Moreover, baleen whales have a **SEXUAL DIMORPHISM**, and males are the one to use vocalization as breeding displays.

It hasn't been observed sound-condcting fats present in odontocetes. Although, there are fat bodies (**EAR FATS**) surrounding the ear lateral to the Tympanoperiotic complex, thus the sound reach the inner ear.



The pattern of their sounds can be described in sequences, repeating series of sound that are separated by **PERIODS** of silent called **GAPS**.

Those are distinct for each animal. **SEQUENCES** are formed by different **PHRASES** (combination of parts) which are repeated in a regular cadence. Between one phrase and other there is the **PERIOD PHRASE**.



Vocalization of a Blue whale [5]

4. FLAWS in the system

ANTHROPOGENIC SOUNDS are a potential impact on cetaceans, and there's been an interest and concert in marine noise pollution (military or commercial ships) and their negative effects by using mid-frequency sounds.
The main objectives are to understand the mechanisms to lead the mortality of these animals, and broaden the knowledge about the role of sound production and reception.

However, some studies realise the possibility of the bottom topography being the silent feature when it comes to stranding. It is been defined a spatially extended acoustical **DEAD ZONES** that make it harder for whales to navigate their way out once trapped, although are just recently hypothesis.

[1] Michelle Spauldin, Maureen A. O'Leary, John Gatesy. Relationship of Cetacea (Artiodactyla Among Mammals. Increased Taxon Sampling Aters Interpretatinons of Key Fossils and Charactr Evolution. Relationships of Artiodactyla, 2009. vol.4.
[2]. Whitlow W.L. Au, Arthur N. Popper, Rchard R.Fay. *Hearing by whales and dolphins Springer* Editors. 2000. Chapter 2.
[3] Joy S.Reidenberg and Jefrey T.Laitman. *Sisters of the Sinuses: Cetacean Air Sacs.* Wiley InterScience. 2008. 291:1389-1396
[4] Joy S. Reidenberg and Jefrey T.Laitman. *Discovery of a Low FFrequency Sound Source in Mysticeti (Baleen Whales): Anatomical Establishment of a Vocal Fold Homolog.* 2007. 290. 745-759
[5] David K.Mellinger and Christopher W.Clark. *Blue whle (Balaenoptera musculus) sounds from the North Atlantic.* 2003. North Atlantic blue whale sounds. . 1108-1118.

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