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Evidence of deafness in a striped dolphin, *Stenella coeruleoalba*

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Abstract

The cetacean auditory system is characterized by a series of unique morphological adaptations, one of the most interesting being the capacity to select frequencies for the fine discrimination of acoustic images through auditory canals, which act like frequency filters. In a healthy organism, this frequency selectivity of the hearing system is directly, and evolutively, related with the habitat use, and thus characterizes every cetacean species. Non-invasive electrophysiological methods allow assessing the hearing system functionality of any particular individual and to determine through the analysis of the audiogram its capacities to correctly use its habitat. Here, we demonstrate the evidence of deafness in a young stranded female striped dolphin, *Stenella coeruleoalba,* which cancelled her possibility to process correctly any acoustic information.

Key words: deaf, *Stenella*, striped dolphin, audiogram, evoked potential, ABR, EP, EFR.

Introduction

Cetacean acoustics, particularly bio-sonar processes, are involved in all odontocete daily activities and constitute a fundamental information exchange basis, either for communication, food location, or orientation in the marine habitat. Although the auditory system of cetaceans has attracted considerable interest, hearing capabilities of cetaceans have been studied for a limited number of species. Most of the available data concern hearing sensitivity (audiograms), which were obtained psychophysically in a number of odontocetes: the bottlenose dolphin, *Tursiops truncatus* (Johnson, 1967), harbour porpoise, *Phocoena phocoena* (Andersen, 1970), killer whale, *Orcinus orca* (Hall & Johnson, 1971; Symanski *et al*., 1999), Amazon river dolphin, *Inia geoffrensis* (Jacobs & Hall, 1972), beluga whale, *Delphinapterus leucas* (White *et al*., 1978; Awbrey *et al*., 1988; Johnson, 1992), false killer whale, *Pseudorca crassidens* (Thomas *et al*., 1988), Risso's dolphin, *Grampus griseus* (Nachtigall *et al*., 1995), Chinese river dolphin, *Lipotes vexillifer* (Wang *et al*., 1992), and Pacific white-sided dolphin, *Lagenorhynchus obliquidens* (Tremel *et al*., 1998). However, the cetacean hearing frequency sensitivity also can be studied with electrophysiological methods, through the analysis of evoked potentials from the head surface. Psychophysical data were actually confirmed by electrophysiological studies in some species: *Phocoena phocoena* (Popov *et al*., 1986), *Tursiops truncatus* (Popov & Supin, 1990*a*), *Delphinapterus leucas* (Popov & Supin, 1987; Klishin *et al*., 2000), *Delphinus delphis* (Popov & Klishin, 1998), *Inia geoffrensis* (Popov & Supin, 1990*b*), and *Orcinus orca* (Symanski *et al*., 1999).

Among a few types of auditory evoked responses described in dolphins (Supin *et al*., 2001), the Auditory Brainstem Response (ABR) represents a particularly useful, consistent and easily recordable phenomenon that can be efficiently used to measure auditory thresholds. However, Evoked Potentials (EP) also can be generated from rhythmically amplitude-modulated tones or tone pulses (Supin & Popov, 1995). This is the so-called envelope-following response (EFR). This stimulation mode and response type have advantages as follows: (i) the level of a rather long tone burst provoking EFR can be specified unambiguously by RMS sound pressure, whereas effectiveness of a single short pulse provoking ABR depends on both its sound pressure and duration and (ii) very low response amplitude to near-threshold stimuli can be measured precisely using Fourier transform and evaluation of the magnitude of a spectral peak at the modulation frequency.

One of the main interests of the present study was to investigate, through EFR recordings, the hearing capabilities of a stranded striped dolphin, *Stenella*

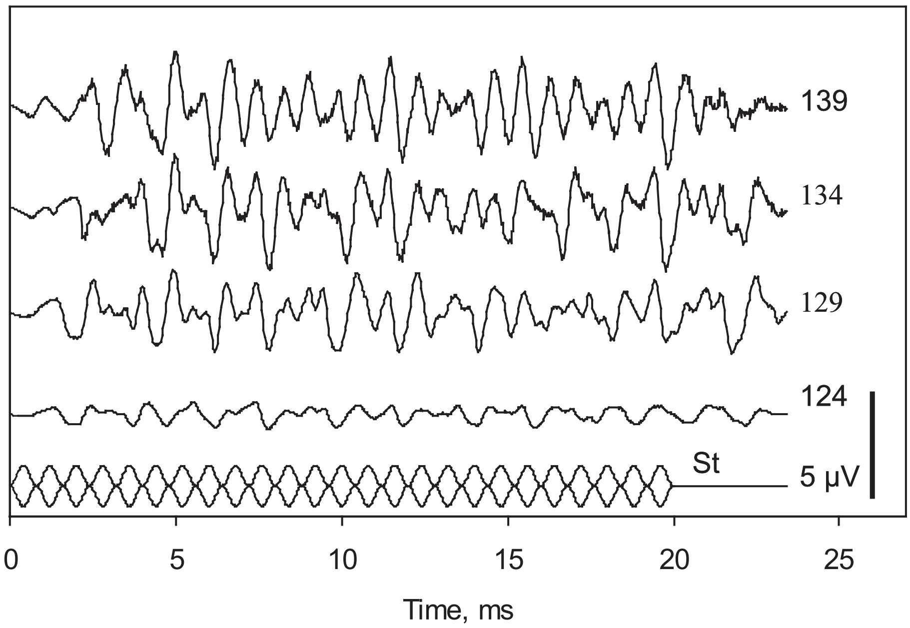

Figure 1. EFR examples at various stimulus intensities. Stimulation conditions: sinusoidally amplitude-modulated bursts, carrier-frequency 64 kHz, modulation-rate 1250 Hz, modulation-depth 100%, burst-length 20 ms (25 cycles), ST stimulus envelope.

coeruleoalba, as a unique opportunity to complete our knowledge on a pelagic species sonar characteristics. However, since an active stranding can be induced by: (i) natural and anthropogenic alterations (pathologies) of the bio-acoustic production and reception processes, which in turn could directly or indirectly influence the cetacean vital systems functionality and (ii) any pathological process associated with a general weakening of the organism which can affect temporally the correct performance of the sonar, together with the species related acoustic characteristics, the investigation of the hearing sensitivity to specific frequencies was also of interest to assess the physiological and/or pathological status of this individual's auditory system and objectively evaluate the relationship between stranding and a possible hearing loss.

Materials and Methods

Subject

'Marisol' was a young female striped dolphin (175 cm) that stranded in August 2001 on the Mediterranean Spanish Southern coast and was rehabilitated in the facilities of Mundomar in Benidorm, Alicante. The clinical examination pointed out a lack of behavioural responses after stimulating the right-side cranial portion, worsened by the complete closing of the right eye (possibly from a traumatic origin), a circle-swim mode and a certain difficulty to dive. Nevertheless, the dolphin was hand-fed correctly (the animal gained weight regularly), white and red blood counts show no parasitic infestation and its vital parameters were remaining at reasonable levels for the species. No sensitive change in behaviour nor in clinical aspects was observed between the stranding and the experiments. No ototoxic drugs were administrated to the animal.

Experimental conditions

The experiments took place between 25 November and 1 December 2001 in the medical tank of the Mundomar facilities. The dolphin 'Marisol' was held in a stretcher made with a sound transparent fabric and fixed at the centre of the pool in a 40- to 50-cm water column. This allowed the dolphin to remain under water while the dorsal part of the head and the blowhole stayed above the water surface. In addition, the choice of placing the stretcher at the centre of the pool (at 2–3 m distance from the closest wall) and dropping the water column down to 40–50 cm, responded to the necessity to prevent acoustic reflection interferences from the bottom and the walls with the recording of the EP (minimizing the echo from the bottom and water surfaces). The experiments lasted for 1–1.5 h, 2–3 times a day, after which the water level was returned to the normal value (1.5 m) and the animal was released.

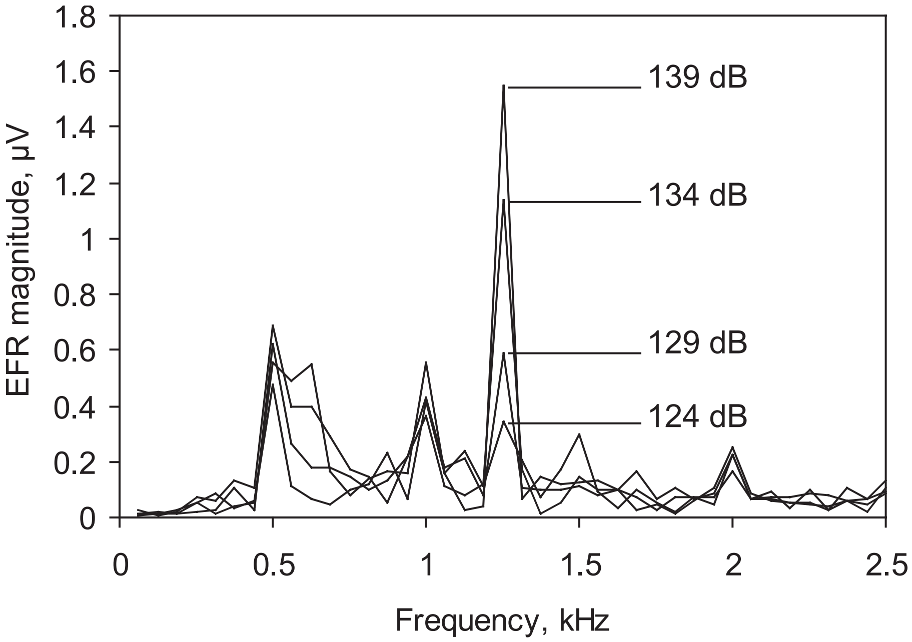

Figure 2. EFR frequency spectra obtained by Fourier transforms of the records exemplified in Fig. 1.

Stimuli

The stimuli used during this study were sinusoidally amplitude-modulated tones, generated by a function generator and amplified by a B&K 2713 amplifier by activation of a piezoceramic transducer (B&K 8104 hydrophone). Their carrier-frequency varied from 16 to 128 kHz. Amplitude-modulated tone bursts were presented in bursts of a duration of 20 ms, modulation-rate (chosen as a result of pilot investigation) was 1250 Hz, modulation-depth 100%. Stimuli were presented at a rate of 20 s^{-1}. The stimulating transducer was placed on the longitudinal head axis at a distance of 1 m from the animal head, at a depth of 20 cm. Stimulus intensity was specified in dB re 1 µPa of RMS sound pressure.

Evoked potential collection

Evoked potentials were recorded using 1-cm disk electrodes secured at the body surface inside 6-cm suction cups. The active electrode was placed at the head vertex, just behind the blowhole. Pilot studies have shown that this electrode position is the most effective for ABR recording. The reference electrode was placed at the back (both electrodes above the water surface). The recorded potentials were amplified within a passband of 5000 Hz (flat frequency response until 3000 Hz, -3 dB at 5000 Hz with 6 dB/oct slope beyond this point), digitized using an A/D converter and averaged using a standard personal computer. The record window was 30 ms long that allowed to record responses to 20-ms long amplitude-modulated bursts and click trains. One thousand sweeps were averaged to collect one evoked-response record.

Sonar production

In addition to these analysis, experiments were conducted to stimulate the spontaneous production of acoustic signals from 'Marisol', when blindfolded with eyecups as well as when directly stimulated with artificial click trains (100 kHz pulses, PRF 100 Hz and SL 160 dB re 1 µPa at 1 m).

Results

EFR characteristics

Sinusoidal amplitude-modulated tone bursts evoked pronounced rhythmic responses which followed the modulation rate—EFR (Fig. 1). The tone burst onset evoked a small transient on-response which after a few milliseconds was replaced by the quasi-sustained EFR. Both the start and the end of the response appeared with a few milliseconds lag relative to the stimulus.

Fourier-transforms of the rhythmic records show a definite peak at the modulation-rate frequency (1250 Hz, Fig. 2). In spite of rather high noise level that manifested itself in significant magnitude of all Fourier components, the 1250–Hz peak could be

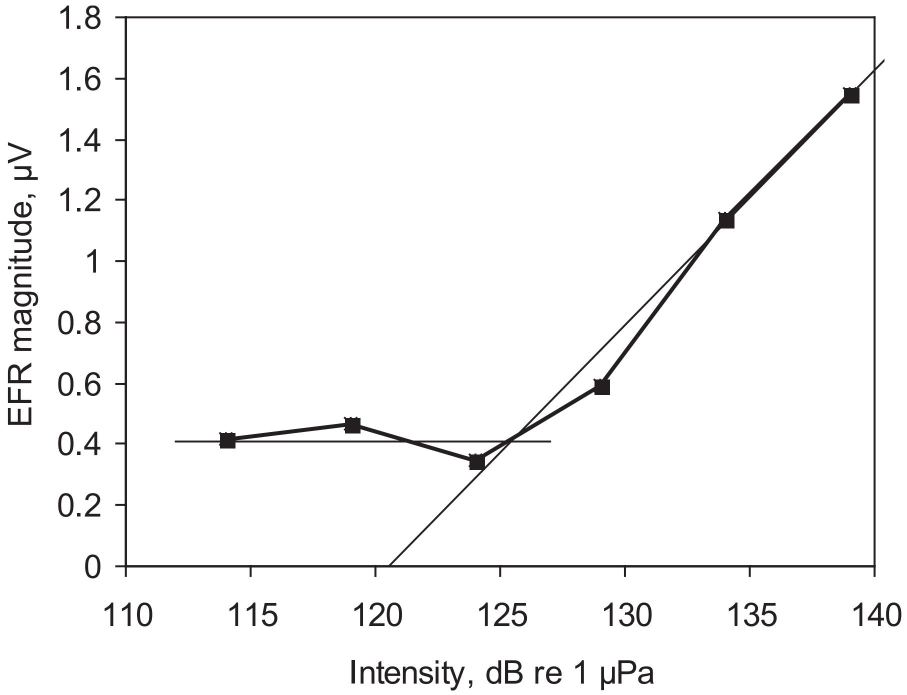

Figure 3. EFR magnitude as a function of sound intensity (obtained by 1250-Hz peak magnitudes of spectra exemplified in Fig. 2). Solid line—experimental data. Thin straight lines—approximation of oblique part of the plot by a regression line (oblique) and mean noise level (horizontal).

confidently identified at suprathreshold stimulus levels.

Hearing thresholds

To measure a hearing threshold at a certain frequency, EFR was recorded to amplitude-modulated tone bursts of that carrier-frequency and of various sound levels, as exemplified in Figures 1 and 2 for a frequency of 64 kHz. Sound level decreased in 5-dB steps until the response disappeared in noise. In each record, a 16-ms long fragment (from 4 to 20 ms after the stimulus onset) was Fourier transformed to obtain frequency spectra, as exemplified in Figure 3. This position of the window for Fourier transform was selected since it contained a major part of the rhythmic response, but did not include the initial transient part of the response.

The magnitude of the peak at 1250 Hz (the modulation frequency) was taken to express the response magnitude in terms of root-mean-square (RMS) voltage. As a result, response magnitudes were obtained as a function of stimulus level for a given carrier frequency. Figure 3 shows a typical EFR-magnitude dependence on stimulus level. Within a certain level range (129 to 139 dB in Fig. 3) EFR magnitude was dependent on stimulus level. At lower levels (114 to 124 dB), the magnitude of the 1250-Hz Fourier component remained constant at a noise level.

Using the magnitude-versus-level function, hearing thresholds were estimated at each of the tested frequencies. The oblique branch of a plot like that in Figure 3 was approximated by a regression line which was extrapolated to the zero response magnitude. This point was taken as a threshold estimate. As an example, the regression line drawn here (Fig. 3) through points from 124 to 139 dB indicated a threshold of 120.1 dB.

In such a way, thresholds were measured at frequencies from 16 kHz to 128 kHz, with half-octave steps (at 90 kHz, the threshold was not determined because of strong record contamination by noise). The resulting audiogram is presented in Figure 4. The lowest threshold estimate (117 dB re 1 μPa) was obtained at a frequency of 45 kHz. Both at higher and lower frequencies, thresholds rose up to 132 dB at 16 kHz and 131 dB at 128 kHz.

In none of the sessions designed to record the sonar behaviour of the dolphin when blindfolded with eyecups, or stimulated with artificial click trains, the dolphin behaviour experienced a change nor any sound was recorded.

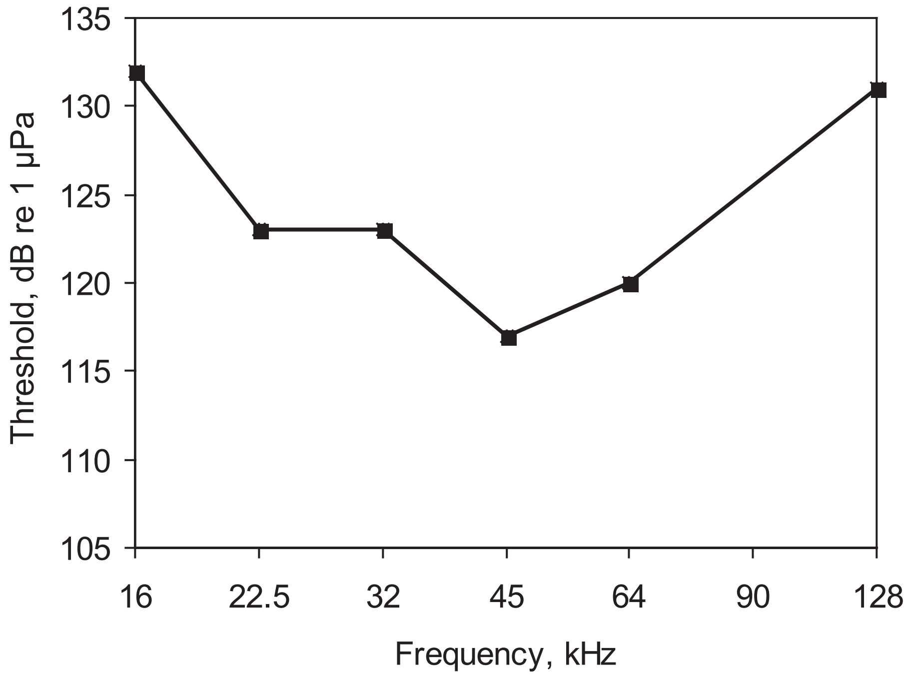

Figure 4. EFR threshold as a function of carrier-frequency (the audiogram).

Discussion

The audiogram from this striped dolphin cannot be considered as a standard for the species. Although there is a lack of audiogram referenced values for the striped dolphin, with the consequent difficulty of accurately quantifying the hearing loss, the comparison with auditory thresholds of other delphinid species (50–60 dB lower at the same frequencies) indicated clearly that this animal could not hear any stimulus which did not go beyond abnormally high intensities. This dolphin found probably herself on the edge of the deafness threshold. The analysis of the results from the experiments conducted to determine the functionality of the sonar system suggests that this dolphin had great difficulties to produce and process correctly any acoustic stimulus, communication or echolocation signals, which related her with her environment. This most likely explains the cause of stranding. Despite the vital parameters and the nutritional state of the animal remained correct during the whole rehabilitation process, this dolphin could probably not correctly perform any basic activity, like feeding, orientation or predator defense, which depends on bio-acoustic processes and would guarantee her survival in her natural environment. This conclusion which suggests for the first time a direct relationship between a cetacean stranding and hearing loss highlights the recommendation of introducing EP measurements and echolocation stimulation as a complementary clinical procedure and a necessary analysis in a cetacean rehabilitation process, not only because they represent a unique opportunity to improve our knowledge on cetacean hearing, but also because this non-invasive procedure constitutes an objective parameter to assess the functionality of the cetacean most critical sensory system.

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