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The effect of acoustic shielding of the region of a dolphin's mental foramina on its hearing sensitivity

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Abstract

The effect of acoustic shielding of the mental foramina of a bottlenose dolphin (*Tursiops truncatus*) on its auditory thresholds has been experimentally studied using the method of instrumental conditioned reflexes with food reinforcement. The detection thresholds of short broadband acoustic pulses deteriorated significantly (by 30–50 dB) under conditions of acoustic shielding in the region of the mental foramina over the whole frequency band of the dolphin's hearing. Therefore, the mental foramina of its lower jaw take part in receiving and conducting the sounds into the mandibular fat in the entire frequency range of the dolphin's hearing. The obtained results give an experimental proof for the assumption that the morphological structures of the lower jaw play a role of the peripheral part of a dolphin's hearing. Now there are grounds to assume that Odontoceti have the similar peripheral part of their hearing. This assumption is based on the similarity of their morphology.

Keywords: Dolphin; Hearing threshold; Mental foramina; Shielding; Acoustics; Lower jaw.

Introduction

The sound conduction mechanisms in the middle ear of toothed whales have been studied in numerous papers. Several researchers of this problem believe that sound travels to the cochlea through the external auditory canal and the middle ear; another viewpoint is that the ear canals cannot at all participate in conducting sound to the middle ear [1] or serve for carrying signals with frequencies below 30 kHz [2]. Other studies suggest that sound can be directly transmitted through the mandibular fat to the tympanic bone, bypassing the external auditory canals and the tympanic ligament [1–4].

Norris suggested [3] that sound can be transmitted to the mandibular fat through the mental foramina. Although this author later advanced another hypothesis about the pathway of sound transmission into the mandibular fat, directly through the posterolateral wall of the mandibular bone, in a specific place he called 'an acoustic window' [4]. Sound is transmitted through the mandibular fat to the lateral wall of the tympanic bone, where its thickness is minimal, and the wall acts as an eardrum, transmitting sound waves to the malleus of the middle ear [3–6]. It was also established that acoustic stimulation of the mandible excites significant evoked potentials in the central auditory system of the dolphin [1,4]. However, Refs.

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[1,4,7,8] disagreed on the location of the area of maximum sensitivity to the sounds emitted by a point source on the surface of the mandible, and the findings do not explain the mechanism of sound conduction.

There is also a number of studies in which the authors claim that toothed whales receive echo signals by their teeth [9]. In these studies, each tooth is regarded as a passive resonator excited by the reflected echo signal and tooth nerves as acoustic pressure transducers. Each row of teeth is considered to be an equidistant antenna array consisting of receivers with a narrow directivity, whose signals are transmitted via the tooth nerves directly into the central nervous system (bypassing the cochlea).

The results of the studies on the subject are thus rather ambiguous and contradictory, and the main question about the mechanisms of sound reception and conduction to the middle ear of toothed whales is currently unanswered. However, the findings of Refs. [10,12,13] suggest that sound travels to the mandibular fat of the dolphin through the mental foramina (MF) of the mandible.

The results of studying the morphology of the dolphin's mandible and the subsequent modeling of the mechanisms of sound reception and conduction through the mandibular canals to the middle ear confirm this assumption. Moreover, in terms of acoustics and the theory of group antennas, each row of the MF acts as an acoustic antenna of the traveling wave, located in the throat of an acoustic catenoidal horn (whose role is played by the corresponding mandibular canal). The concept of the mandible as a system of two traveling wave antennas explains the mechanisms of reception and conduction of sound to the middle ear. In view of this, the morphological structures of each of the halves of the lower jaw (mental foramina, mandibular canal and mandibular fat) are treated as the components of the hypothetical peripheral division of the dolphin's hearing.

The purpose of this study is to experimentally explore the role of mental foramina in the dolphin's hearing. The specific tasks consisted of determining the effect of acoustic shielding of mental foramina on the auditory thresholds of detecting acoustic pulses with peak energies at different frequencies.

The subject of the study, materials and experimental procedures

The experiments were carried out at the T.I. Vyazemsky Karadag scientific station – Nature Reserve of RAS (Feodosia) in an enclosed concrete

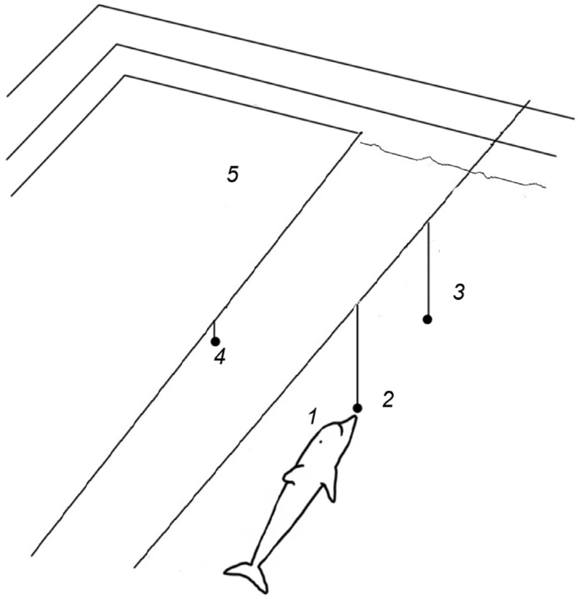

Fig. 1. Experimental setup: dolphin *1* in the starting position, start arm *2*, transducer of acoustic stimuli *3*, signal arm *4*, experimenter's walkway *5*.

$27\,m \times 9\,m \times 4.5$ m-sized pool. An adult Black Sea bottlenose dolphin (*Tursiops truncatus*) who had not previously participated in acoustic experiments acted as the experimental subject. We employed the technique of instrumental conditioned reflexes with food reinforcement using the 'go/no-go' paradigm [14].

On a signal from the trainer (position *5* in Fig. 1), the dolphin was trained to swim to the walkway, where the trainer placed (or did not place) a sound-shielding hood on the rostrum of the animal in the MF area. After that, the dolphin was signaled to swim to start arm *2* suspended at a depth of 1 m, and remained at that depth with almost no movement (quasi-stationary), touching the tip of the start arm with its rostrum. After a few seconds the experimenter turned on the auditory stimulus (shown in Fig. 2) that the dolphin found (or did not). If the stimulus was produced and the dolphin found it, the dolphin left the starting position (go) and pressed its rostrum against signal arm *4* (located near the surface of the water), thus indicating that it had found the stimulus. If the stimulus was not presented, the dolphin remained at the starting position until receiving a signal from the trainer (no-go). In these cases, the dolphin received food reinforcement for correctly solving the problem. If necessary, the trainer removed the shielding hood from the dolphin's rostrum for that purpose every time. The cases when a stimulus was produced but the dolphin did not approach the signal arm, or there was no