INTERFERENCE IMMUNITY OF THE DOLPHIN'S *TURSIOPS TRUNCATUS* SONAR TO NARROW-BAND INTERFERENCE

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1. ABSTRACT

The data base of the dolphin acoustic activity patterns exhibited under the conditions of the narrow-band interference was created. Monofrequency signals with frequency 50 kHz, 80 kHz and 100 kHz were used as noise. According to the analysis of phonograms, animals used only multipuls mode of echo-location in all the tests performed. Signals consist of packets. The number of clicks in the packet is equal to 2¸3 and does not depend on the level of the acoustic pressure of noise. The clicks are grouped in time. They have a broadband form with an undefined spectral maximum, the click trains assuming the form of a superbroadband signal.

KEY WORDS: dolphin, marine bioacoustics, acoustic behavior, interference immunity, signal detection.

2. INTRODUCTION

Natural echolocators are characterized by high plasticity. Therefore studying echolocation behaviour of the dolphin in various acoustic conditions of laboratory experiment is of great scientific interest. Analysis of the obtained data on echolocation characteristics of the dolphin has shown that high echolocation capacity is achieved due to the adaptive mechanisms providing optimization of the echolocation process in solving various behavioural tasks.

A review of the results obtained in laboratory experiments in an open cage can be found in [1]. The comparison of the acoustic activity of animals in laboratory experimental conditions with that of animals in the sea shows that the repertory of acoustic activity in natural conditions is much richer than in laboratory experiments [2].

Data obtained in the research of echolocation signals aimed at detection of a sphere of 8.7 mm was carried out in laboratory experiments affected by noise of the frequency band 10□23 kHz an changing level of sound pressure from 0 to 14 Pa are presented in [3]. The amplitude of probing pulses rises sharply at the moment of noise introduction, and frequency of emitting pulses decreases if level of the sound pressure of noise decreases. The presence of noise did not influence the process of detection of the target or spectral structure of echolocation signals.

Spectral tuning away of sounding radiation from interfering effects was studied in [4]. Interfering noise in the frequency band 1-150 kHz at a sound pressure of 900 Pa and the monochromatic one (30 kHz and 80 kHz) at a sound pressure of 540 Pa. were applied. In all experiments the energy maximum of the spectrum of echolocation pulses was shifted to the lower frequency range 35□50 kHz. The background occurrence in the of the monochromatic noise of with a frequency of 30 kHz or of a pulse with a basic frequency of 30 kHz and sound pressure of 120 Pa caused a shift in the spectral maximum of signals emitted by the animal towards the high frequency range 65-85 kHz.

In phenomenological experiments on recognition of simple geometrical figures with recording dolphin's signals, it is shown that the dolphin purposefully changes the structure of echolocation pulses [5]. In this experiment, radiators of noise are set directly on the dolphin's head close to ear apertures. Duration of transmitted pulses increases, if noise interferes. The spectral analysis of echolocation pulses has shown that the spectrum of pulses is narrowed and shifted depending on the level of sound pressure and spectral structure of noise.

In experiments on discrimination of spherical targets on the background of band noise [6] it is shown, that the shape of the energy spectrum of pulses transmitted by the dolphin, in the presence of noise practically does not differ from that in its absence. Band noise in the range above 116-146 kHz, below 46-73 kHz and in the frequency band of the spectrum maximum of echolocation pulses 73-116 kHz were used in the experiments as noise interference.

In the experiments on detection of spherical targets [7] on the background of noise, emitted by a special device placed at a distance of 14 m from the animal, no temporal or spectral changes characteristics of pulses have been revealed. It is shown, that increased sound pressure of noise causes a sharp rise (up to maximum 222 dB, relative 1 μPa) in the sound pressure of pulses transmitted by the dolphin.

Thus, in laboratory experiments on detection tasks in the presence of noise, the dolphin's ability to purposefully change the level of sound pressure and pulse recurrence rate was proved. Recurrence rate of pulses varies depending on the distance to object of search and level of interference sound pressure.

The purpose of this research was to study echolocation behaviour of toothed whales in difficult acoustic conditions of laboratory experiment. The Black Sea dolphins of species *Tursiops truncatus ponticus* were used as research object.

3. METHODS

The experimental procedure corresponds to the technique of alternate selection under successive stimulus presentation with an acoustic control over animal's behaviour during the experiment. The technique developed includes the measurement of the parameters, such as the animal orientation in the cage relative to the coverage sector, the alternate selection (yes/no) under successive stimulus presentation and the motor reaction of the animal to both target presence and target absence. The method of corroboration of animal's reaction to all conditional sensory stimuli, including the zero stimulus (corresponding to the target detection problem), commonly used in psychoacoustic experiments and described in the literature as the method of the forced yes/no choice [8] and was applied.

The dolphin was allowed to select the duration of insonifying the coverage sector, the decision time, and the orientation of the body relative to the object of detection, which significantly decreased the volume of acoustic data for further processing.

Figure 1 schematically shows the geometry of the experiment to narrow-band interference. The experimental compartment was supplied with a special window looking toward the bay. Unlike the cage nets, the window of size 2 x 3 m was shielded with a net with a 25 x 25 cm mesh. The compartment was equipped with the starting manipulator-annunciator (fig.1; M1) at a distance of 1 m from the window and two reaction-token manipulators at distances of 1.5 m to the right (fig.1. M2 – target yes) and to the left (fig.1. M3 – target no) from the starting manipulator.

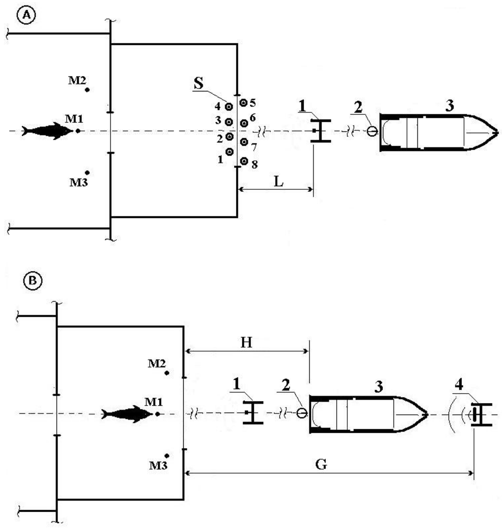

Fig.1. Schematic representation of the experiment on detection of underwater objects with artificial interference: A– forming of a barrage (narrow-band interference); B– forming of a (narrow-band) interference behind the target; M1,M2, M3 - manipulator; S_{1-8} – piezoelectric sonic projectors; 1- piezoelectric hydrophone; 2- target; 3- boat; 4 – beam transmitter of the narrow-band interference

We carried out two experiments a day. The duration of an experiment was about two hours. In the experiment, the dolphin received a food fee for 3 to 10 correctly fulfilled successive tasks, which made it possible to increase the number of tests in one experiment without degrading the food motivation. We guided the animal's behavior using the annunciator, which generated acoustic signals and transmitted them into water via a radiator (this annunciator served simultaneously as the starting manipulator). The annunciator used four signals (F1, F2, F3, and F4) with a carrier frequency of 50 kHz and respective modulation frequencies of 0.5, 1, 1.5, and 2 kHz.

In the experiments, we used the following test order:

- as the experimenter produced the signal F1, the animal stood at the start position near the manipulator M1 in the surface layer and oriented the body at an angle of 90° to the direction of search;
- via the radio channel, the experimenter informed the operator about the distance at which the boat should be located, the kind of the target to be used, and the target depth in the current experiment;
- in accordance with the protocol of the experiment, the target was either submerged in water to the specified depth or left at the surface;
- the tape-recorder was turned on for operation in the recording mode, and the experimenter gave the signal F2, which meant the start of search;
- on signal F2, the dolphin turned toward the searching sector, submerged into water and started the location process;

- one to three seconds after making a decision, the dolphin pushed the corresponding manipulator;
- if the task was fulfilled correctly, the experimenter gave the signal F3 to inform the animal about the success; otherwise, the experimenter gave the signal F4;
- the tape-recorder was turned off.

The receiving hydrophone was positioned on the line of animal's starting position, in the middle of the water layer (2 m) at a distance of 50 m from the cage. Both preamplifier and hydrophone were mounted on an anchored floating platform. As the hydrophone, we used a Ø5 mm transducer whose average sensitivity was 7 μV/Pa. The preamplifier with a gain equal to 5 was used as the matching device between the acoustic transducer and a 60 m long cable. Via this cable, the signal from the preamplifier was fed to the amplifier and the recording system. The above depths and the distance to the receiving point were chosen reasoning from the fact that the structure of the sounding pulse varies only slightly within ±2° at the level of 0.7 of the directional pattern of the dolphin's acoustic field. We recorded the signals of the dolphin by an MP-3. The flatness of the amplitude-frequency characteristic of the receiving channel was better than 3 dB in the frequency band of 0.5-200 kHz.

In the experiment, the noise field was formed by two ways. The first was realized by means of a barrage, which was formed by 8 not fixed transmitters located at a distance of 7 m from the animal's start position (Fig.1-A). In the second case the interference was formed behind the target at a distance of 220 m from the open-air cage put on the (Fig.1-B). We used a Ø100 mm piezoelectric projector, consisting of a set of converters oriented in one plane as the directional projector. Objects of search of different targets force were presented from the boat at a fixed distance of 200 m from the open-air cage. The experimenter communicated with the operator via a radio channel.

The reflectance of the shapes used (i.e., the target reflectivity) was calculated from the experimentally measured sound pressures of radiated and reflected signals in the sea for different distances to the target. Detection experiments in the noise field were carried out for two objects with target reflectivity T1 =-1.6 dB, T2 =-14 dB.

Recording of signals with the tape recorder was carried out at the minimum level of sound pressure of noise (122 dB) with a gradually increasing level of noise up to the maximal value.

4. RESULTS AHD DISCUSSION

Training of the dolphin was carried out under the conditions of a broadband interference. The first presentation of the broadband interference with a level of sound pressure 90 dB caused stress reaction in the trained animal. The dolphin refused to carry out tasks known to it during 7 days of the experiment. Within the next 30 days the animal adapted to the influence of the broadband interference for the level of sound pressure varying from 60 dB to 145 dB.

The registered amplitude of the sound pressure of echolocation pulses did not exceed 220 dB. The amplitude of the sound pressure of radiated (emitted, projected) pulses in the experiments did not depend either on the level of the sound pressure of interference or its spectral structure.

Changes in the intervals between echolocation pulses in the course of the target search in the presence of the narrow-band interference handicap are shown in Fig. 2. The presented data include the entire pulse sequence in one test.

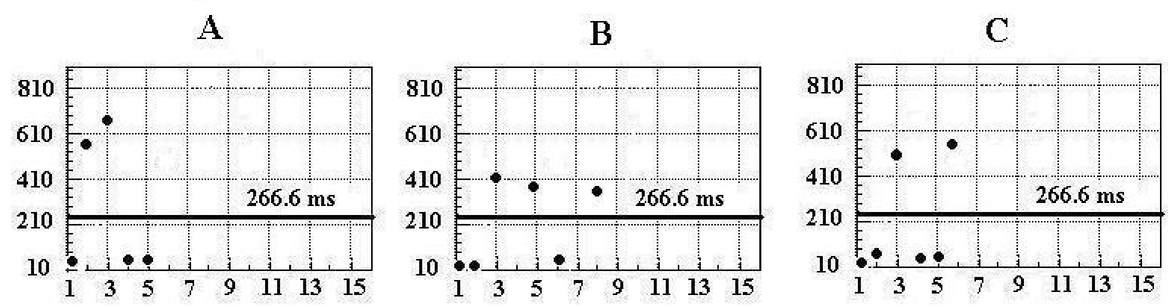

Fig.2. Dynamics of the temporal pulse sequence versus the pulse-to-pulse interval number in narrow-band interference: A– narrow-band interference 50 kHz; B – 80 kHz; C –100 kHz; the pulse-to-pulse interval is plotted as the ordinate in ms; the interval number in sequential order is plotted as the abscissa; the heavy line shows the time required for the signal to travel to the target and return back

The results obtained are evidence of the availability of two operating modes in animal's radiating system: the single-pulse mode and the mode of transmitting pulse groups (bursts). Each burst consists of two or three pulses. Duration of a pulse burst varies from 10 ms to 50 ms the time interval between pulses in a burst is not constant. The time interval between pulse bursts is greater than the time taken by the signal to travel to the target and return back. Research of the macrostructure of the pulse sequence shows that before data processing it is necessary to find a parameter, which would be invariant to changes in the modes of location.

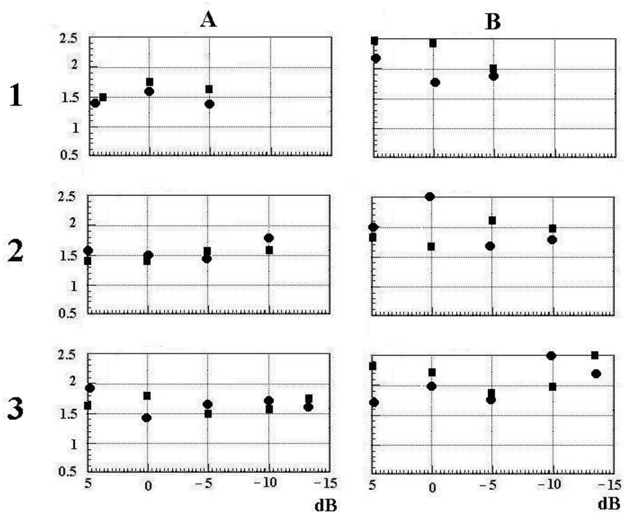

Fig.3. Dependence of the overlapping factor on the presence of a narrow-band interference: the overlapping factor is plotted as the ordinate; the ratio 10log (E/N) is plotted as the abscissa in dB; A - correct detection; B - correct non-detection; point -target with target reflectivity equal to -14 dB; square - target with target reflectivity equal to -1.6 dB

To generalize the single-pulse and multipulse echolocation modes, we introduce the concept of overlapping factor defined as the ratio of the pulse-to-pulse or burst-to-burst interval to the calculated time of signal propagation to the target and back: $K = T_{exp}/T_{calc}$. In this formula, the denominator T_{calc} is known and depends on the distance between the dolphin and the target, and numerator T_{exp} is obtained from the experimental data. In the case of the single-pulse echolocation mode (for distances of 120¸150 m), the value of T_{exp} can be easily assessed on the basis of experimental data. In the case of the multipulse echolocation mode, the time is determined as $T_{exp}=\Sigma t_i + t_k$. Here Σt_i is the sum of pulse-to-pulse intervals in a burst (the burst duration) and t_k is the interval between the last pulse of the burst and the first pulse of the next burst. The pulse sequence characterized by the overlapping factor much smaller than unity can be classified as a burst of pulses.

As seen from Fig. 3, the overlapping factor in the situation correct of detection lies within the limits 1.3-2 having the average value of 1.5. In the situation of correct non-detection the spread in values of the overlapping factor of much greater: 1.6-2.5. In some cases it exceeds 3. Such a spread in the values of the overlapping factor is explained by the fact that in the absence of a target the dolphin for the sake of reliability examines much bigger space than in the presence of a target. This is supported by the quantity of transmitted pulse bursts in one test.

In the situation, when there is no target, the dolphin radiates from 3 to 5 pulse bursts, whereas in the presence of a target, as a rule, this number is 1-2. Comparing modes of operation of the echolocation system when the object of search is situated at a distance up to 200 m [9, 10] and when the narrow-band interference is handicaps shows, one can see that the mode of operation in bothe cases is the same. This testifies to the fact that the narrow-band interference handicaps does not affect jamming immunity of the dolphin's echolocation systems. As it was assumed, unlike in technical systems using phase-manipulation [11], the use of superbroadband signals increases jam-immunity of the dolphin's echolocation system, as a whole, from the narrow-band interference. The results presented are not final since the level of the transmitted interference was limited by characteristics of the radiating hardware complex.

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