BIOACOUSTICS
The influence of ultrasound on animal irritation

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Sometimes it is necessary to chase certain animals from places important to men. One among many methods is the acoustical method – sound, particularly ultrasound, is used to accomplish enough irritation in animals to chase them. Some mammals are more suitable for this method according to their good hearing in the ultrasound range [1]. As the absorption of sound in air increases with frequencies, low ultrasound frequencies should be used. The influence of experimental ultrasound signals on the appearances of irritation in rats and dogs was measured. The first test signal was a simple sine, and the second a swept sine. In both experiments animal irritation was obtained at 10 dB less sound pressure level with the swept sine than with the sine signal.

INTRODUCTION

There are various reasons why people must repel certain animals from areas where they can harm people or destroy valuable goods (protecting corps from insects, airports from birds, home yards from cats and dogs, basements and stores from rats, tourist areas from mosquitoes, etc.). This goal can be achieved in different ways using different methods. We can distinguish between electrical, chemical, mechanical, optical, acoustical methods, etc. The advantages of the acoustical method comparing to others are: inexpensive to use, not harmful to animals and safe for people using it. This is true under the assumption that ultrasound is used, which is inaudible for people and does not cause any hearing damage, even when exposed to sound pressure levels up to 120 dB [2]. The restriction is that only animals with good hearing in the ultrasound region can be repelled by this method.

MEASUREMENTS

The influence of high intensity ultrasound on rats and dogs was measured. Test signals were generated using an ultrasonic generator and a piezoelectric loudspeaker capable of reproducing ultrasound up to 50 kHz. The whole test setup was calibrated in an anechoic chamber by means of SPL, frequency and directivity characteristics. Having in mind which signals ultrasonic chasing devices use for repelling animals, in the first case a simple sine signal was used which could be altered in frequency (20 to 35 kHz) and amplitude, and in the second case a swept sine from 20 to 35 kHz, also changeable in amplitude.

The sound irritation threshold was measured on 6 grown albino laboratory rats type "Fisher" from the same breed (3 female and 3 male) of average physical characteristics. They were not given any water for a day to become thirsty. Every animal was placed during the measurement in a separate cage where it could drink water at the front side of the cage, fig. 1. When the animal came closer to the water bottle to drink, test signals were turned on and increased in sound intensity until the animal refused to drink because it was irritated by the sound. Typical signs of irritation were: running to the back of the cage, digging into the wooden sawdust, running in circle, "cleaning" the head with the front paws and "freezing", all of this being also described in the literature, [3]. It is important to state that the animals could not be harmed because when they felt that the sound became to irritating, they showed one of the described behavior pattern. At this moment the sound source was immediately turned off. The measured thresholds of irritation are shown in fig. 2 and 3 only for the male rats, similar results are obtained for the females.

FIGURE 1. Test setup for irritation measurements of rats.

FIGURE 2. Threshold of irritation for male rats using the sine test signal.
FIGURE 3. Threshold of irritation for male rats using the sweep test signal.

If the obtained results for both test signals are compared, it can be seen that irritation appears for 5-10 dB lower SPL if the swept signal is used rather than the sine signal. Obviously, the efficiency of the test signal rises if the frequency varies, thus making impossible that the rat gets used to the repelling signal. Another interesting fact is that the obtained data match well inside the tested group of animal. This is important to assure the efficiency of this repelling method.

A similar procedure to investigate the sound irritation threshold was used for dogs. There were 11 test dogs available of different breeds and ages. They were placed into individual cages. The test equipment was placed approximately 50 cm in front of the cage, fig. 4. The test signals were switched on one by one and increased in sound intensity until the dog showed signs of irritation. That included opening the mouth (reflex reaction to open the Eustachian tube), lowering the head, rotating the head from the sound source as well as the whole body and finally, retreating of the animal to the back of the cage.

FIGURE 4. Test setup for irritation measurements of dogs.

The results obtained by this experiment, shown in fig. 5 and 6, can lead to a similar conclusion as for the rat experiment. The sweep signal is more effective than the sine signal because the irritation can be obtained at 5-10 dB lower SPL. There is a greater scattering of the results because the dogs were not of the same breed and age. For some frequencies no results could be obtained which leads to the conclusion that some dogs could have hearing damage, or aging hearing loss.

FIGURE 5. Threshold of irritation for dogs using the sine test signal.

FIGURE 6. Threshold of irritation for dogs using the sweep test signal.

CONCLUSION

The obtained results show that it is possible to use ultrasound for achieving irritation in animals. However, this is useful only if the animals have good hearing in the ultrasound region (rats or cats). If the animals hear only lower ultrasound frequencies, it is possible that this method will be not enough effective to repel them because of the decreased sensitivity to this frequencies as well as the loss of hearing in the higher frequency region with age (dogs). There are also differences in hearing between different breeds. All of this should be considered when building ultrasonic chasing devices.

REFERENCES

Acoustic Activity of Sturgeons

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Acoustic activity data of 6 Sturgeons species were cited including parameters of signals of sevruga Acipenser stellatus, ship A. nudiventris, Russian sturgeon A. gouldenstadti, Siberian sturgeon A. baeri, see sturgeon A. sturio, beluga Huso huso; acoustic activity dependence of the state of adult fish readiness to spawn; and Correlation of juveniles fish acoustic activity with the state of fish health disorder and/or environment.

MATERIALS AND METHODS

The study of acoustic activity of four species Sturgeons was carried out after induced maturation at Russia hatcheries.

Underwater acoustic signals were registered by a piezoceramic hydrophone and video recorder Panasonic NV-S7 S-VHS-C in the frequency range from 0.1 kHz to 20 kHz with dynamic range 90 dB.

Recorded acoustic signals were analysed with the PC based system “Biooptima” (St.Petersburg, Russia).

The following parameters were obtained: oscillogram (amplitude-time), spectrogram (amplitude-frequency) including summary and instantaneous spectra, dynamic spectrogram or sonogram (amplitude-frequency-time) and sonogram numeral data.

Using these data of frequency modulated signal; the most precision algebraic equation was determined to show how the signal frequency varies depending on the time.

To study behaviour in response of sturgeons to sounds, three sound signals of Russian sturgeon were emitted by the transducer. Nine fifteen-minute emissions were carried out in the basins with males, females and juvenile females of Russian sturgeon and females of sterlet Acipenser ruthenus, 1 with juvenile females of sturgeon.

RESULTS

Observations on acoustic activity in six sturgeon species showed that juveniles and adults are among the most "silent" fishes. However, they produce acoustic signals when their physiological state is changed.

Spawn Acoustic Activity

During prespawn and spawn periods males and females of all studied sturgeon species emit species specific sounds like whistle and frequency range and produce the following four types of signals:

1. "High-frequency wide-band" signal have wide continuous total and instantaneous spectra in the range from 2 up to 20 kHz.
2. “Low-frequency wide-band” signal have wide continuous total and instantaneous spectra in the range from 0 up to 12 kHz.
3. “Series of pulses” consists of 4 - 25 pulses with duration 1 - 30 ms. The frequency spectrum of pulse is continuous in the range of 2 - 20 kHz.
4. "Whistles" of sevruga consists of 1 – 7 harmonics with duration from 10 ms up to 1000 ms. The frequency of the first harmonic is 2 - 4 kHz, the highest harmonic is up to 14 kHz. (Tolstoganova, 1996).

In our bioacoustic observations in situ in June 1983 in the River Volga 100 “whistles” of sevruga have recorded during spawn period. These whistles recorded together with very high noises however, we have essential components of sevruga signals were revealed in frequency spectrum in the range of 7-9 kHz. (Tolstoganova, 1996).

Ship whistle consists of one 3 frequency modulated components which frequency increases an exponential rate. The number of whistle signals produced during the time period is correlated with the state of fish readiness to spawn (Tolstoganova, 1997a).

Siberian sturgeon A. baeri consists of 1 - 5 frequency modulated components which varies directly as the square or cube of time. Summary spectrum of these signals is continuous or bands spectrum in the range of from kHz up to 18 kHz. Instantaneous spectrum is line or band (Tolstoganova, 1997b).

Whistles of Russian sturgeon consists of 1 – 3 components the frequency, which varies inversely as the square root of the time. Most often Russian sturgeon produced “FM whistles” having one component. While this signal was emitted by transducer fish movement activity of
both sexes of Russian sturgeon increased and some fishes sharply changed their way towards the transducer and approached it. The behaviour of sterlet females and juvenile females of Russian sturgeon was not changed while any signals of Russian sturgeon (Tolstoganova, 1999).

**Juvenile Acoustic Activity**

Juvenile sturgeons do not emit sounds under normal maintenance conditions. But once some days before fish mortality suddenly increased by unknown reasons, “Series of pulses” had been registered. These impulse signals consist of from 1 to 20 pulses with duration of 1 to 5 ms.

Similar biosounds had registered during the studies of behaviour reaction of beluga *Huso huso* juveniles upon changes in water salinity. The juveniles emitted “Series of pulses” in only salt water. However, the results of the experiment showed that acoustic activity depended more on the factor ”Fish” than the factor “salinity” or factor ”changing salinity”. We supposed that some fish consumed bad feed. For testing this assumption we carried out a study an acoustic activity of Beluga juveniles when they were fed on different diets including semitoxic with 76% infuzoria living and toxic feeds with 40% infuzoria living.

Being fed on toxic or semitoxic feeds the juveniles produced impulse and short “whistle” signals with duration 20 to 100 ms. The number of signals is correlated with state of feed toxic and this feed amount consumed before. During non-toxic feeding juveniles, do not emit any sounds.

Between whiles toxic or semitoxic food feeding juveniles did not produced sound signals. During non-toxic feeding juveniles, fed just with toxic or semitoxic food did not produced sound signals too.

Moreover, when the water pump had suddenly broken and oxygen concentration in water decreased from 7.8 mg/l to 5.3 mg/l, the juveniles, fed with toxic or semitoxic feeds, produced 0.1 to 0.3 signals per specimen/ minute. At the same time juveniles, fed only on non-toxic feeds, produce no acoustic signals.

**CONCLUSION**

Spawning signals spectrum of all sturgeon species has components in frequency range from seven up to 20 Hz. These data promise to create acoustic method and equipment for find spawn sites.

The observation of Russian sturgeon behaviour during sound signals were emission by the transducer showed that it is possible to attract fishes by acoustic signals of own spesies, for example, to man-made spawning site.

Adult sounds were only recorded during pre-spawning and spawning periods. Juveniles produced sounds when they were diseased or their health was compromised and/or environmental conditions had deteriorated.

Acoustic activity depends on the degree of readiness of an adult fish to spawn. Acoustic activity correlates with the level juveniles health disorder and/or environment. The above data give hope for the creation of an acoustic method and equipment for locating spawning sites, remote control of spawning both in hatcheries and the wild and the timely detection of diseased fishes from a distance. During our bioacoustic observations in situ “whistles” of sevruga have been registered in distance up to 500 m revealing essential components of sevruga signals in the range of 7-9 kHz.

The detailed study acoustic activity dependence on health disorder state of aquatic organism and environmental conditions can be used to design the acoustic equipment for remote controlling these states and revealing ill fishes in the real time.

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**REFERENCES**


Tolstoganova L.K. Correlation between acoustic activity and physiological state in some sturgeons. 20th conference of European comparative endocrinologists. 5 – 9 September 2000, Faro, Portugal, Abstract Book, p.79.

Time resolution capability of the dolphin

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The Black Sea bottlenose dolphin’s auditory time resolution of 17-18 µs is discussed. The time resolution was estimated as a minimum delay of the click relative to the onset of the noise pulse just detectable by the dolphin.

There is a notion that the dolphin’s auditory time resolution is an equivalent of the dolphin’s auditory integration time [1, 2, 3]. Although dolphins have a very short sonar click, the auditory frequency tuning and integration processes are thought to preclude the sonar from reaching a theoretical time resolution of its sonar click. Dolphin’s auditory analysis of click signals seemed to be sufficiently described with only one time constant of around 300 µs, which is considered to be the auditory time resolution [3], as well as the auditory integration time constant [1].

The theoretical time resolution constant of the echolocation clicks of about 15 µs, in combination with broad hearing range of around 100 kHz, can provide the dolphin with the time domain target discrimination cues. Although such a high auditory time resolution seems impossible, there is an estimate of the dolphin auditory time resolution of 20-30 µs [4]. In this presentation new measurements of the time resolution of the dolphin auditory system will be discussed. The time resolution was estimated as a minimum delay of a click relative to the onset of a noise pulse detectable by the dolphin.

METHOD

The subject was an adult Black Sea bottlenose dolphin. The experiments were conducted in a 28 × 13 × 4 m concrete pool using a two-response forced choice paradigm. A vertical net partition between two transducers (piezoelectric ceramic spheres with 1.5 cm in diameter) set a minimum distance of 5 m, from which the dolphin made his choice. The transducers situated at 3 m from each other, at 1-m depth. The signals were presented simultaneously through both transducers.

Prior to stimuli presentation, the dolphin positioned itself at the far end (away from the transducers) of the partition. Having made its choice the dolphin approached the chosen transducer. The dolphin discriminate between the signals combined of the noise pulse and click with different delays of the click relative to the noise pulse onset (figure 1). The duration of the noise pulses was 70 µs. In order to reduce spectral differences between stimuli in our early experiments with dolphins we replaced correlated double-clicks with noise double-pulses [4]. There was yet a chance that the dolphin discriminated between the double-pulses with different interpulse intervals in the frequency domain.

The replacement of the noise double-pulses with the stimuli in figure 1 was a next step to eliminate differences in the frequency spectra. Because the noise pulse duration was larger than both click delays, rare notches in the frequency spectra of the stimuli associated with the click delay were masked with the dense notches associated with the noise pulse duration. However, in the time domain the dolphin was presented with the same task of discriminating between time intervals, namely between different click delays.

FIGURE 1. Waveforms of the stimuli for a 10-dB signal-to-noise ratio for energies.

FIGURE 2. Amplitude spectra of the stimuli shown in figure 1. Y-axis is logarithmic, expressed in dB.

A stimuli repetition rate was 3 per second. The click had a peak frequency between 100 and 120 kHz (figure 2). The dolphin was required to approach the transducer
of the stimulus with a shorter click delay. In the first series of experiments, maximum and minimum threshold signal-to-noise ratios were measured as functions of a longer click delay (figure 3). A smaller delay was 7 \( \mu s \). For a given longer click delay, the amplitude of the noise pulses varied during the experiment to determine the minimum and maximum threshold ratios for the energies of the click and noise pulse.

In the second series of experiments the minimum delay of the click relative to the onset of the noise pulse was measured. The signal-to-noise ratio for energies was 10 dB.

**RESULTS**

The dolphin was able to discriminate between the stimuli for the signal-to-noise ratios within the range in between two plots in figure 3.

Because no regular ripples, which could identify the position of the click in the noise pulse, were present in the stimuli spectra, the dolphin appeared to discriminate between the stimuli in the time domain. There was no energy cues, too simply because the energies of the stimuli were equal. A significant change in the threshold ratios for delays below 37 \( \mu s \) (figure 3) may indicate an approach to the auditory time resolution.

For a shorter click delay from 0 to 10 \( \mu s \) the threshold longer delay was found to be around 17-18 \( \mu s \) (figure 4). For a shorter delay of 15 \( \mu s \), the threshold longer delay was 22-23 \( \mu s \). It looked as if the dolphin did not discern the click delay shorter than 15 \( \mu s \) relative to the noise pulse onset. The stimuli seemed to be different for the dolphin as one, which had delay and the other, which had no delay at all.

The dolphin was also able to determine position of the click in the noise pulse when discriminating between the noise pulse without the click and that mixed with the click. When the delay was shorter than 25 \( \mu s \) the dolphin chose the noise pulse mixed with the click as a positive stimulus, otherwise he approached the transducer transmitting the noise pulse without click. It appeared that the presence of the click with a shorter delay in comparison stimulus somehow helped the dolphin to measure the longer delay.

**FIGURE 3.** Maximum and minimum signal-to-noise ratios for energies as functions of a longer click delay. A shorter delay was 7 \( \mu s \).

**FIGURE 4.** The minimum longer delay as a function of a shorter delay.

The shortest detectable by the dolphin delay of the click relative to the noise onset gives the estimate of the dolphin’s auditory time resolution of around 17 \( \mu s \), the highest estimate so far.

Clearly, there was no signal integration in the auditory system, at least beyond 17-25 \( \mu s \). With the integration time constant as big as 264 \( \mu s \) [1], the dolphin would fail to discriminate between the signals because they had the same energy. The high time auditory resolution was not limited by the integration processes in the auditory system. On the contrary, when the task required from the dolphin a very high time resolution, the dolphin appeared capable of shutting the auditory integrator off.

**REFERENCES**

Localization of sounds from a paired source in the dolphin and fur seal

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An auditory “echo suppression” phenomenon was investigated in the Northern seal and the Black Sea bottlenose dolphin. The seal’s perception of two underwater sounds coming from different directions proved to be similar to human’s perception of a paired source in air. The “echo suppression” phenomenon was not found in the dolphin, either at 100 kHz or at 10 kHz.

There is a notion that the dolphin’s spatial hearing is similar to that of humans. A binaural hearing model is used to explain sound localization in the dolphin. However, the dolphin’s ability to localize a source in the vertical plane, in the absence of interaural differences, is practically the same as in the horizontal one [1].

There are different hearing phenomena in humans associated with the binaural perception of the sound coming from two different directions. Due to a so-called auditory “echo suppression” phenomenon, the echoes in a reverberant room are not heard [2]. For delay between 1 and 30 ms, so long as the delayed sound is 10 dB below the primary sound, the echo source are not perceived acoustically. A direction, in which the integrated sound is heard, could be different from position of two sound sources. We investigated whether the binaural “echo suppression” phenomenon is present in the fur seal and the bottlenose dolphin’s auditory system.

METHOD

The subjects were the Northern fur seal and two Black Sea bottlenose dolphins. Three broadband (6-100 kHz) magnetostrictive transducers were separated by net partitions as shown in figure 1. The lateral transducers were seen from the animal’s position at 60°. First, the animals were trained to detect a single pulse transmitted through the one of the randomly chosen transducers and approach it. Next, two sound pulses of the same intensity would be transmitted though the lateral transducers with some delay relative to each other. the animals were required to approach a transducer of a primary sound. Minimum and maximum delays (at a 75% correct response level) between the sounds, were measured.

In some trials, the intensity of a delayed sound was higher than that of a primary sound. If there is the “echo suppression” phenomenon in the animal’s auditory system then at some combination of a delay and an intensities of the sounds from lateral transducers, the animal should approach a middle silent transducer. Animal’s approach to any transducer in this case considered to be correct, so that the animal would not be trained to a certain response. 10-kHz tone pulses with duration of 1.5 and 3 ms were used with the seal.

The same 10-kHz tone pulses were also used in the experiment with dolphins. Additionally, 0.1-ms and 1-ms tone pulses of 100 kHz, and high frequency broadband clicks were tested. 1.5-cm spherical piezoelectric transducers were used.

FIGURE 1. Configuration of the experiment.

Given the directionality of the dolphin’s hearing at high frequencies [3], there could be a chance that the “echo suppression” phenomenon functions only within the receiving beam pattern. Therefore, we also investigate the dolphin’s response to a sum of 100-kHz tone pulses, for the angle between two transducers as small as 3°. The sensation level of the signals was 40 – 46 dB. Different stimuli repetition rates from 2 to 10 per second were tested.

RESULTS

The fur seal

The minimum and maximum delays between the primary and delayed sounds, at which the seal approached the transducer of a primary sound were found to be 0.25- 0.35 and 25-30 ms, respectively.

For a zero delay between the sounds and equal sound amplitudes, the seal approached a silent middle transducer when the sounds were transmitted through the lateral transducers.
For a 3-ms delay, so long as a delayed sound was no more than 10 dB intense than a primary sound, the seal approached the transducer of a primary sound (figure 1). On the graphs this corresponds to a very small percentage of the approach to a silent middle transducer. Further increase in intensity of a delayed sound caused the seal to approach a silent middle transducer. As the intensity was increased to 20 – 24 dB above primary sound the seal began to approach the transducer of a delayed sound. In figure 1 this shift is again indicated by less than a 20-% approach to the middle transducer. For a longer tone pulses the changes in seal’s response occurred at a higher intensity of a delayed sound.

For a 60 o-angle between the lateral transducers, we could not find, as we easily did with the seal, a delay and an amplitude ratio, at which the dolphins would approach a silent middle transducer.

Thus, the fur seal’s auditory system is characterized by the binaural “echo suppression” phenomenon similar to that known for humans.

The dolphin

In the same experimental conditions both dolphins never approached a silent middle transducer when the sound pulses were transmitted though both lateral transducers, either at high frequency of 100 kHz, or at 10 kHz. For a zero delay and equal amplitude of the sounds the dolphin randomly approached one of the lateral transducers.

For delays between high frequency clicks longer than 0.25-0.3 ms the dolphins in a short time learned to approach the transducer of a primary click. However, the maximum delay, beyond which a delayed click supposedly to be heard, changed with the click repetition rate, remaining around one third of it. For example, for stimulus repetition times of 100 and 500 ms the maximum threshold delay was around 28 and 160 ms respectively. Therefore, the measured maximum delays were not the audibility thresholds of the delayed sound, but rather the discrimination thresholds between the primary and delayed sounds.

By increasing the amplitude of a delayed sound it was easy to make the dolphins change a positive stimulus; they begun to approach the transducer of a delayed sound for all tested sounds. The threshold amplitude difference was found to be around 1.8 dB at any delay. It seems unlikely that such a small difference in amplitudes could cause the merged image of two sounds to shift to the transducer of a delayed sound. Moreover, it was possible to retrain the dolphins to approach the source of a primary sound for any delay from 0.3 to 15 ms and the amplitude difference as big as 34 dB. It is clear that discrimination between the sounds by both delay and amplitude, at the same delay and difference in the amplitude, is only possible if the sources are perceived separately in time and space.

For a 60 o-angle between the lateral transducers, we could not find, as we easily did with the seal, a delay and an amplitude ratio, at which the dolphins would approach a silent middle transducer.

At the angle between the lateral transducers of 3 o, the dolphins was also able to switch from intensity to delay discrimination and back to the intensity cue again. In other words, the amplitude and delay of the sounds did not interact in the dolphin’s auditory system and could be assessed by the dolphin independently. It means that even within the dolphin’s receiving beam pattern the “echo suppression” phenomenon, is not present in the dolphin’s auditory system.

Thus, in contrast to the northern seal, two sounds coming from different directions did not produce in the dolphin a single imaginary source either at high frequencies or at low audio frequencies. It might be expected that the dolphin’s hearing at high frequencies, especially associated with very short echolocation clicks, would differ from a low frequency binaural hearing in humans. Surprisingly, the dolphin’s spatial hearing at low frequency is very much different as well.

REFERENCES

An Old World Symphony: Vocal Acrobatics in a Chinese Frog

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The vocal repertoire of a small treefrog from Anhui Province, China appears to be rather unique in that no two calls emitted by an individual are identical. Moreover, many of the calls contain ultrasonic components and other unusual vocal features such as sudden frequency shifts and temporal overlapping of acoustic elements that suggest the possibility of multiple sound sources in this extraordinary frog.

Although most amphibians are highly vocal, they generally emit a limited number of acoustic communication signals. Recent studies have brought to light several exceptions to this rule. In particular, in one population of the House Treefrog studied in Western Thailand, males of \textit{Polypedates leucomystax} may produce up to nine distinct vocalizations [1]. An endemic Madagascar treefrog, \textit{Boophis madagascariensis} (family Rhacophoridae), has the largest known anuran vocal repertoire reported to date, with 28 distinct call types that differ both in temporal patterns and spectral bandwidth [2]. Despite this call diversity, frequency modulation of the carrier in frog call notes tends to be unidirectional, i.e., either upward or downward, but not mixed as often occurs in vocal signals of songbirds and primates [3,4].

We report here the extraordinary richness of the vocal repertoire of \textit{Amylops tormotus} (Ranidae), found only in selected regions of China. These frogs produce countless vocalizations some of which share features of birdsong or primate calls, e.g., ultrasonic frequency components, FM warble notes, simultaneous occurrence of non-harmonically-related upward and downward FM sweeps, and sudden onset and offset of selective components within a call note.

\section*{METHODS}

\textit{Amylops tormotus} is a locally-abundant arboreal frog restricted in its distribution to Mt. Huangshan, Anhui Province (type locality) and to Jiande and Anji counties in adjacent Zhejiang Province, Peoples Republic of China. It inhabits shores of streams in mountains and hills at elevations from 150-700 m. Males call from sunset to about midnight from shrubs, saplings, fallen tree branches or grass. Males of this species are unique in that the eardrums are located at the medial end of a cavity, deeply sunken into the skull. This cavity appears to be an air-filled chamber directly outside the external surface of the eardrum with an unobstructed opening at the body surface.

Males of \textit{Amylops tormotus} were studied in Huangshan Hot Springs, The Peoples Republic of China. This is a mid-elevation (alt. 640 m) mixed deciduous forest dominated by Mao bamboo and \textit{Fagus engleriana}. Mean annual rainfall at this site is 239 cm. We observed these animals calling nightly from the low vegetation along the steep banks of the Tai Hua Creek (30° 06' N, 118° 10' E) from sunset to nearly midnight from 20 May to 2 June, 2000.

Vocalizations of 21 individuals of \textit{A. tormotus} were recorded using a directional microphone (Sennheiser ME-66) placed within 1.5 m of the calling male and a portable cassette recorder (Sony TC-D5M). For most calls, peak sound pressure levels were recorded using a calibrated (GenRad 1987 minicalibrator) impulse precision sound level meter (GenRad 1982, fast detector, max. hold feature) with the center frequency of the octave band filter set at 4000, 8000 and 16,000 Hz. In addition peak ambient noise levels were measured over 10-s intervals for filter settings of 31.5, 63, 125, 250, 500, 1000, 2000, 4000, 8000 and 16,000 Hz. Ambient temperature for all recordings was between 20.0-24.4 °C.

Acoustic playback experiments were performed in which one of three representative calls (1A, 1B, 1C) of a male of the population was used as the stimulus. These calls were stored in separate files in a portable computer (Macintosh G3) from which they were played through a portable powered speaker (Sony SRS-A60) located within 1.5 m of the male under test. Stimulus playback levels were adjusted by ear to match those of the males’ calls, and were calibrated subsequent to the experiment with the powered speaker placed 1 m from the sound level meter (GenRad 1982, fast detector, max. hold feature), and using the inverse square law to
estimate sound pressure levels at the position of
the frog under test.

Both spontaneous and evoked vocalizations were
digitized (44.1 kHz sample rate, 16-bit) using Canary
software (Version 1.2.4, Cornell University
Laboratory of Ornithology, 1998) and stored as
individual files on the MAC computer (Powerbook
G3). An FFT (2048 points) of each file using a 699
Hz analysis filter bandwidth produced amplitude
spectra that revealed important features of the calls’
fine structure. Calls were then categorized according
to the degree of frequency modulation and harmonic
structure exhibited.

**RESULTS AND CONCLUSIONS**

Fig. 1 illustrates a single vocalization from a
representative male *A. tormotus* in the study
population, given in response to the playback of
the species-specific call. None of the other vocalizations
recorded from any of the 21 males studied was
identical to this one. This utterance exhibits several
unusual features not previously reported for
amphibian vocalizations. Especially noteworthy is
the presence of simultaneous yet non-harmonically-
related acoustic elements, suggesting the possibility
of multiple acoustic sources in this animal.

Single-frame video analysis of this frog’s calling
behavior reveals that *A. tormotus* possesses one pair of
lateral vocal sacs and a second pair of sub-gular vocal
sacs. In theory, air passing between these sacs could act
as a second sound source, complementing the vocal cords
to produce the extraordinarily diverse vocal repertoire of
this remarkable frog. Ongoing analysis is attempting to
verify or refute this hypothesis.

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**REFERENCES**

1. J. Christensen-Dalsgaard, T. A. Ludwig and P. M.
2. P. M. Narins, E. R. Lewis and B. E. McClelland, J.
3. F. Goller, and R. A. Suthers, J. Neurophysiol. 76, 287-
300 (1996).
4. J. Fischer, M. Metz, D. L. Cheney and R. M.
Two types of the bottlenose dolphin’s echolocation clicks

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Two different types of echolocation clicks were found in the Black Sea bottlenose dolphin. The typical echolocation clicks recorded in all tested dolphins were similar to that of the Atlantic bottlenose dolphin. Two of the dolphins also transmitted unusual sonar clicks with the peak frequency between 120 and 130 kHz and very broadband frequency spectra. Irregularities in the time domain waveforms and ripples in the frequency spectra suggest that the unusual clicks were produced with two sound sources.

The Atlantic bottlenose dolphin was found capable of controlling frequency spectra of its sonar clicks [1]. Generally, as the click source level increased above 210 dB re 1 µPa, the frequency spectra became bimodal, with two energy peaks at 30-60 and 100-130 kHz. The results suggest that the dolphin’s ability to control the frequency content of the clicks is restricted by the click generation mechanism.

In this presentation we will discuss two types of the sonar clicks of the Black Sea bottlenose dolphin.

METHOD

A 5-channel recording system was used to record waveforms of the dolphin’s clicks from a screen of a 5-channel oscilloscope. The hydrophones were distributed horizontally or vertically behind targets. Three automatic cameras were used to record the clicks from the scope screen, and the dolphin position in the vertical and horizontal planes so that for each click the position of the dolphin head relative to the hydrophones was known. The cameras were triggered by the dolphin click. Broadband cylindrical hydrophones were specially designed and manufactured by the Moscow Acoustical Institute for experiments with dolphins [2]. The frequency response of the hydrophones was flat within 3 dB from 10 to 160 kHz. The sonar clicks of several dolphins were recorded during different experiments on detection and discrimination of targets. The records of the clicks were made in a concrete pool 20 x 10 x 3 m and later in a larger pool 28 x13 x 4.5 m using a two-response forced choice paradigm. The targets were presented simultaneously at each side of a vertical net partition that set a distance of 7 m between the dolphin and targets. The dolphins were trained to stay at the start position under the cameras and echolocate the targets.

RESULTS

All the dolphins emitted so-called typical echolocation clicks presented in figure 1. The lowest source level observed in our experiments was around 170 dB re 1 µPa. In the present of the masking noise the source level of the clicks could reach as high as 226 dB. The typical dolphin clicks had a peak frequency between 100 and 120 kHz.

Two of the examined dolphins transmitted both typical and unusual sonar clicks. If the typical echolocation clicks can be described as an exponentially damped sinusoidal wave with a duration of 20-30 µs, the unusual clicks have a much more complex and variable waveform and a frequency spectrum spreading beyond 250 kHz. The frequency spectra of the unusual clicks were even broader than frequency range of the hydrophones. In order to record the second type clicks without frequency distortion, we used the Selesco LC-5 hydrophone with a flat frequency response up to 700 kHz (a central channel in figure 2).

The irregularities in the waveforms and frequency spectra of the unusual clicks recorded with LC-5 hydrophone are more conspicuous than that recorded with the rest of the hydrophones. The frequency spectra most of the unusual clicks were rippled with period of 80-160 kHz. The presence of the ripples in the frequency spectra suggest that the clicks were produced with two generators delayed relative to each other. This delay is also indicated by a fracture in the time domain waveforms of the unusual clicks (figure 2, central channel). The duration of the unusual clicks varied from around 25 to 45 µs. The variability of the unusual click parameters might be a result of a limited synchronization between the two generators.

We later found that both nasal plug nodes, which insert into the opening of the tubular sacs were polished in the dolphin that transmitted the unusual clicks. In two other examined dolphins, which transmitted only typical sonar clicks, the right node was polished too, but the left node was covered with a thin epithelium-like layer. The condition of the plug node surface may point to the tabular sac as a possible generator of the sonar clicks. If this is the case, then the unusual clicks might be produced by two simultaneously working tubular sacs.
FIGURE 1. Two consecutive typical bottlenose dolphin clicks recorded in 5 different directions in the horizontal plane. Sweep length is 130 µs.

FIGURE 2. Two consecutive unusual clicks recorded in 5 different directions in the horizontal plane. Sweep length is 130 µs.

FIGURE 3. Amplitude spectra of the clicks shown in figure 2. Each row in the table is the spectra of the same click recorded in 5 different directions in the horizontal plane. The number near each spectrum shows the direction on the hydrophone relative the dolphin’s head axis.

We could not find any connection between the type of the sonar clicks and the echolocation task. The dolphins used both types of clicks for any of tested targets and noise conditions. They could use different types in different sessions or switch from one type to the other during the same session.

REFERENCES