Original text: Priroda, 2013, № 4, p. 20-26 (in Russian).

SPANISH DEER AND SPANISH SINGER

Ilya Alexandrovich Volodin, PhD, Associate professor of Laboratory Animal Behaviour, Cathedra of Vertebrate Zoology, Lomonosov Moscow State University. Research field: social behaviour of mammals and birds, mechanisms of sound production, bioacoustical monitoring of populations.

Elena Vladimirovna Volodina, PhD, zoologist of Scientific Research Department of Moscow Zoo. Research field: call structure and function, individual and sex-related differences of vocalizations.

Tomas Landete-Castillejos, PhD, director of an experimental deer farm of University of Castilla La Mancha (Albacete, Spain), vice-director of the Institute of Regional development of Castilla La Mancha, the singer (tenor). The area of scientific interests: ethology, biocommunication, biomechanics of bone tissues, formation of singing voice.

Emiliano Aviles, professor of Musical Academy «Amadeus» (Albacete, Spain). Expert in the area of singing performance mastership, the singer (baritone). The area of scientific interests: the role of anatomy and physiology of the vocal apparatus in establishing a professional singing voice.

Roland Frey, PhD, works in the Institute of Zoo and Wildlife Research (Berlin, Germany). The specialist in the area of evolutionary morphology and comparative anatomy; is studying adaptations of mammalian vocal tract under the influence of sexual selection.

The mastership of professional singing is a relatively rare capability among people. To have a nice voice is still not sufficient. Even the most talented singer should learn for a long time, until he would capable of possessing the full potential of the voice. Also, there is a concept of singing longevity. Incorrect singing can result in broken vocal folds rather than in claps.

Even most outstanding teachers of vocal mastership cannot explain in brief, what means "to sing correctly". Nearly 600 pages of a textbook by a professor of Moscow Conservatory V.P. Morosow were devoted to this problem. He synthesized his 45-year-long experience of studying the singing techniques of famous vocalists (F. Shalyapin, S. Lemeshev, I. Kozlowsky, I. Arkhipova, E. Obraztsova, E. Nesterenko, I. Bogacheva, V. Atlantow, P. Lisician, N. Gyaurov, E. Karuzo, M. Kallas, P. Domingo, L. Pavarotti and many others) [1]. The main resume of this book is short "use the resonance!" But how it should be used?

We decided that the best way learn, how to use the resonance for singing, is to ask the natural singers, who are just incapable to spare without the resonance: male red deer (Cervus elaphus). During the rut, their roars deter rivals and attract females. The stag not calling loud and beautiful calls for a prolonged time, loss chances for breeding in the current season. So, all red deer stags should be wonderful singers.

Basses and tenors

Techniques of rutting singing of deer stags are different, depending on the area. Among them, there are basses, tenors, and even those who are capable of calling bass and tenor simultaneously or glide from upper to lower notes in a graceful glissando*. These different «vocal classes» rose during evolution of red deer. Fossils along to DNA-analyses of extant red deer suggest that they originated in Central Asia and then distributed in two opposite directions. Those deer who went to the West, gave rise to all modern European red deer [2], and those who travelled to the East, gave rise to Siberian elk, Far-East elk and to American wapiti. By currently unknown reason, all Western red deer call exclusively bass [3—5], whereas all the Eastern ones vocalize with high piercing descant [6—8].

Classic and modern

All stags use the vocal resonance, but differently. The Western bass subspecies use it in accordance to the classical source-filter theory. The vocal folds of the larynx serve as voice source, and the vocal tract above them (involving the pharyngeal, oral and nasal air cavities) serves as the vocal filter [9]. From physical viewpoint, the vocal tract of any mammal represents a pipe of certain diameter and length. Each pipe has its own resonance frequencies, and the sound, passing through the pipe, enforces non-uniformly.

The areas of enforced sound by resonances of the vocal tract termed formants. The main postulate by source-filter theory is the independence of source and filter. This means, that sound filtering by the vocal tract does not affect the vibration frequency of the vocal folds and therefore does not change the frequency of the created sound.

Male Spanish red deer produce different call types. In harsh roars, where the fundamental frequency is masked with chaos, the filter-related features (formants) are well-visible (Fig.1, right) [3, 5, 10]. Otherwise, in common roars, the source-related features are well visible. Those are the fundamental frequency and its harmonics, looking at the spectrogram as a pile of frequency bands (Fig.1, left). The lowest of the bands is the fundamental frequency, which coincides with the vibration rate of the vocal folds. Harmonics are integer multiples of the fundamental frequency.

The effect of filtration of the sound by the vocal tract is well noticeable at the beginning of the spectrogram, in the form of the running down formants. This occurs, when the stag retracts the larynx at the beginning of the roar down to the sternum. This results in strong elongation of the vocal tract and changes its resonant frequencies. Formants start decreasing when follows passively the decrease of the resonant frequencies of the vocal tract. When approaching to the middle of the call, formants are becoming invisible. This is because formants can only enforce the energy, that is already presents in the call. The formant is becoming invisible, if it falls between harmonics, because the acoustic energy between harmonics is lacking. But when the formant falls on the harmonic, it is also becomes invisible, because it is becoming undistinguishable from the harmonic. This is because formants could be seen most clearly either in low-frequency calls, with closely spaced harmonics, or in noisy calls, where sound energy dispersed over the call spectrum as a cloud (see. Fig. 1).

Unlike stags of Western subspecies of red deer, the stags of Eastern subspecies vocalize high tenor (Fig. 2). These strange piercing sounds can hardly be termed "roars". For them would be better to use the English term "bugle". So far is enigmatic, how the Eastern red deer produce their bugles. Their 3-centimeter vocal folds should be tensed so strongly that should be broken invariably [10—12]. Maybe, there is another mechanism here, which enables emitting such high calls without the extreme vocal fold strain?

Such mechanism, based on the power of resonance, is applied in many wind instruments. For example, in organ, the sound source is represented by a small thin reed, which itself is incapable of producing loud sound at vibration, as vocal folds by red deer. All the organ power is achieved due to multiple enforcements, when the reed starts vibrating at one of resonance frequencies of the organ-pipe [1]. Is it possible that wapiti trumpet as wind instruments? Computer modeling approach predicts that yes [12]. Such tuning mechanism, named otherwise source-filter coupling, can increase the sound pressure level of 10 decibel, what means that the sound will become twice louder [13]! However, so far nobody observed this acoustic effect in real calls of a live deer.

How to manage howling siren

To do that, it is necessary to break off the independence of voice source and voice filter. In this case, the sound of the vocal folds can "couple" with one of formants. The interaction between source and filter forces vocal folds to vibrate at the frequency of the formant. Exactly this effect occurred in one Spanish stag (Fig.3, left). We found only a single such sound among nearly 3 thousand roars, recorded from many tenses Spanish stags. This suggests extreme rarity of this acoustic phenomenon in Spanish red deer [10]. But among other mammals source-filter coupling is also exclusion rather than the rule. Really, so far this effect was known only for humans, for vocal exercises of soprano singers [14]. Also, one of the authors of this article (Emiliano Aviles, professional teacher of vocal and baritone singer) could reproduce sounds with very similar siren-like resonance, imitating calls of this Spanish stag (see Fig. 3, right).

Along to similarity between sounds of the deer and the man*, there was an essential difference between them. The stag was capable of manipulating the length of its vocal tract at the larger extent compared to the man. The human singer, with help of his muscles, could only to tilt and descend slightly the larynx. This provided only a small elongation of the vocal tract. The stag, with help of its muscles and the extensible, as an elastic band, especial connective tissue, was capable of retracting the larynx down of 25 cm, up to anchoring before the sternum.

This could be the reason, why in the deer, the vibration rate of the vocal folds could be tuned to the fourth formant of the vocal tract (F4), whereas in the singer it could be tuned only on the first formant (F1). Apart of this, in the stag, the formant turned into a new fundamental frequency with own harmonics. So, in the stag, namely the vocal tract (the filter) determined the fundamental frequency, as in wind musical instruments.

Distinctively, in the man, the filter passively enforced the fundamental frequency and the harmonics in places, where they coincided with vocal tract resonances (see Fig. 3). From physical and bioacoustical viewpoints, this was not source-filter coupling, but the tuning of the source on the frequencies of the filter. The same mechanism use white-handed gibbons for producing their very loud territorial songs, resound to a couple of kilometers in dense tropical forests [15]. However, gibbons enforce selectively the fundamental frequency. Distinctively, the man could enforce also harmonics, coinciding with respective formants.

Why the source-filter coupling is so rare in Spanish red deer? Theoretically, the vocal tract of deer can be considered as a hollow pipe [3]. Resonance (formant) frequencies of such vocal tract can be calculated with a formula $Fn = (2n - 1)*(C/4L)$, where n — the number of the formant, c —the speed of sound (350 m/s for warm humid air) and L — the length of the vocal tract. As male deer vocalize through the widely opened mouth, we should take for calculations the oral vocal tract, comprising 765 mm in male Spanish red deer at maximum retraction of the larynx [5].

In calls, filtrated by such vocal tract, the lowest expected formant is 114 Hz, what is much lower than the fundamental frequency (on average, 186 Hz). In such calls, the source-filter coupling cannot occur with the fundamental frequency, and is possible only between formants and widely spaced harmonics. So, the probability, that one of the harmonics will «coupled» with one of formants is rather low.

But in extremely high-frequency bugles of Eastern deer, the distance between harmonics is even wider, however it seems this does not prevent them from the using source-filter coupling! Probable, male Siberian elk and American wapiti rely here on their retractable larynx. In this case, it helps not only elongate the vocal tract, as in Western red deer, but also to establish the coupling with a certain formant.

This is the case, for example, when a musician playing trombone moves an especial slide mechanism (U shape-pipe), to change the air volume in the wind instrument. Even during the most fast moving of the pipe when playing legato, sound slips will be inevitable heard at transitions between tones, because the trombone uses the source-filter coupling.

Similar effect can be seen at spectrograms of the bugle. When wapiti stag is raising the frequency of the bugle, the characteristic «steps» appear (see Fig.3).

But the siren-like resonance has nothing to do with the professional singing voice. This is one of numerous mistakes of beginning singers, which teachers of singing advice to avoid. However, the highest mastership of the teacher is not only avoid of mistakes when showing, how to sing. The highest mastership is to repeat any mistake of the pupils, and explain on the own example, how not to sing!

Legend to Figure 1. Spanish red deer stag and spectrogram of rutting roars: common (left) and harsh (right). In the first case, the fundamental frequency and its harmonics are well visible; in the second case, the formants are well visible. The fundamental frequency represents the rate of vibration of the vocal folds, which is depicted as the lowest dark band on the spectrogram image of the roar. A pile of integer multiple bands above the band of the fundamental frequency represent harmonics. Harmonics always appear, when vocal folds are working; they will appear even if the vocal tract resonators (pharynx and nasal or oral cavities) will not be presented. The axis X shows time in seconds, whilst the axis Y shows sound frequency in Hertz (one Hertz if one oscillation per second).

Legend to Figure 2. Siberian elk stag and spectrogram of the rutting bugle. Formants are unnoticeable, because the fundamental frequency is very high, and the distance between harmonics is very large. At rise and fall of the fundamental frequency, characteristic steps are visible. The axis X shows time in seconds; the axis Y shows sound frequency in Hertz.

Legend to Figure 3. Spectrogram representing siren-like sounds of Spanish red deer stag (left) and of Spanish singer (professor of singing and the baritone, Emiliano Aviles). Both the deer and the singer use superficially similar vocal approaches. They both start from the usual singing, in which the fundamental frequency corresponds to the rate of vibration of the vocal folds. Then both vocalists tune the voices on one of formants of their vocal tracts (the deer on the 4th formant, the singer on the 1st formant). As soon as they did, the voice started sound as siren, an its intensity increased abruptly either in the deer or in the singer*. This can be seen by the increase in the amplitude of oscillations on the waveform above each sound.

* Call of red deer stags of different subspecies can be heard at web-site http://www.bioacoustica.org/gallery/mammals_rus.html#Artiodactyla