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# BIOACOUSTICS OF SINGING CICADAS OF THE WESTERN PALAEARCTIC: *TETTIGETTA BRULLEI* (FIEBER 1876) (CICADOIDEA: TIBICINIDAE)

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**Abstract** - *Tettigetta brullei* (Fieber 1876) is one of the Mediterranean cicadas, singing in the high frequency range, which is present in Slovenia as well. The calling song of the solitary male consists of two phrases with repeated patterns. Typically, the 250 - 500 ms long phrase type 1 consists of a long echeme (LE1, duration 175±41 ms), followed in most cases by 2 - 4 short echemes (SE1, duration 5 - 6 ms). Phrase type 2 (duration 320 - 560 ms) again consists of a long echeme (LE2, 273±41 ms), followed by one longer short echeme (SE2, 60±6 ms) or without it (30% of phrases). Sequences of phrase type 1 can switch to phrase 2 without any interruption. The basic pattern of the calling song consists in both phrases of 4 clicks, representing the in- and out- buckling of the left and right tymbal, shifted for 0.8 - 1.3 ms. We present the main temporal parameters qualitatively and quantitatively. The spectrum of the calling song contains two main frequency bands: a dominant one between 14 and 22 kHz with a maximum at 16 - 20 kHz, and a secondary peak between 7 and 10 kHz, which is at least 10 dB lower in amplitude compared to the main peak. The frequency range extends into the ultrasonic range at least up to 25 kHz. The use of ultrasonic ("bat") detectors is therefore very helpful for field work with this species.

**Izvleček** - BIOAKUSTIKA POJOČIH ŠKRŽATOV ZAHODNEGA PALEARKTIKA: *TETTIGETTA BRULLEI* (FIEBER 1876) (CICADOIDEA: TIBICINIDAE)

Škržat *Tettigetta brullei* (Fieber 1876) je eden izmed manjših pojočih škržatov, razširjenih v Sloveniji, za katere je značilen visok frekvenčni pas oglašanja na človekovi zgornji slušni meji. Pozivni napev samcev te vrste sestoji iz dveh podobnih ponavljajočih se fraz (fraza 1, 2), ki lahko brez prekinitve preideta druga v drugo. Tipično sestoji fraza 1, katere cikel traja 250 - 500 ms, iz dolgega ehema (LE1, trajanje 175±41 ms), ki mu večinoma sledita 2 do 4 kratki ehemi (SE1, trajanje 5 - 6 ms). Fraza tipa 2, katere cikel traja 320 - 560 ms, tudi vsebuje dolg ehem (LE2, 273±41 ms), ki mu večinoma sledi en krajši ehem (SE2, 60±6 ms), v 30 % primerov pa ta manjka. Trajanje razmika med dolgimi ehemi je pri obeh frazah tisti časovni parameter, ki najmanj variira. Osnovni element vseh zvočnih signalov pri tej vrsti je sestavljen iz štirih pulzov, ki najverjetneje predstavljajo časovno zamaknjene (0.8 - 1.3 ms) tranziente ob vbočenju in izbočenju levega in desnega timbala. Glavne časovne parametre napevov prikazujemo kvalitativno in kvantitativno. Spekter obeh fraz pozivnega napeva obsega dominantni frekvenčni pas med 14 in 22 kHz, z vrhovi med 16 in 20 kHz ter sekundarni, vsaj za 10 dB nižji stranski vrh emisije med 7 in 10 kHz. Emisija sega v ultrazvočno območje vsaj do 25 kHz, zato je uporaba ultrazvočnih ("netopirskih") detektorjev za ugotavljanje prisotnosti teh škržatov pri favnističnem delu zelo priporočljiva.

## Introduction

*Tettigetta brullei* (Fieber 1876) is characterized by the most high-frequency songs among palaearctic singing cicadas, hardly audible for unaided human ear even at short distances of 1 - 2 m. Therefore, and due to protective coloration and different forms of escape behavior, this species is much less studied in all respects - starting from general biology, ecology, spatial distribution and acoustic behavior.

To study them, we used a special method (see below), which allowed us to detect singing males from a distance of tens of meters. During our studies it appeared that these cicadas are widespread and numerous in the warm regions of Slovenia and Croatia, and during summer months their songs are one of the most characteristic features of the soundscape there. According to Schedl (1986) and Duffels & van der Laan (1985), *Tettigetta brullei* is generally present in the western and eastern Mediterranean regions from Spain to Greece. With the special method mentioned we recently detected it also in Macedonia (FYROM - our unpublished data).

In this paper we continue our descriptions of acoustic signals of singing cicadas from the western Palaearctic (Gogala et al., 1996, Gogala & Popov, 1997) with this small species of *Tettigetta*. Boulard (1995) briefly described the song of *Tettigetta pygmea* (Olivier, 1790), which is not discernible from the song of *T. brullei* recorded by us. According to M. Boulard, who kindly compared the specimens of *T. brullei* from

Slovenia with *T. pygmea* from France, they belong to one and the same species and the name *pygmea* is older. Nevertheless, we still use in this paper the Fieber's name *T. brullei* following the nomenclature of Duffels & van der Laan (1985) and Schedl (1986) (see Discussion).

## Material and Methods

*Tettigetta brullei* (Fieber 1876) belongs to a group of small cicadas producing high-frequency sounds. Their anatomical features are shown in Fig. 1 and it is evident that they have tymbals and tympana typical for tribus Cicadettini.

These cicadas usually inhabit bushes and trees especially at the forest borders or single bushes in the meadows. Unlike *Cicadetta tibialis* (Gogala et al., 1996: p. 48), they were never observed singing on the grass.

To detect them, we used an ultrasonic ("bat") detector Ultra Sound Advice S-25, the microphone head of which was mounted above the center of Telinga parabola (Fig. 2). Thanks to this method we could easily localize them from distances of up to 50 m and found that they were singing not only on bushes but quite often even on tops of high trees (oaks).

Songs of cicadas *Tettigetta brullei* (Fieber 1876) (= *Tettigetta pygmea* (Olivier 1790), Boulard 1995) used in these analyses were recorded in the warmer regions of Slovenia (Karst and seaside) during summer months 1994-97. All recordings were made during the daytime at temperatures of 27° to 35°C. Songs of 17 animals (with the best quality of recordings, at least 30 s long), were used for evaluation here.

The acoustic recordings were made in the field using digital techniques in the sonic range between 20 and 22000 Hz with SONY DAT-corders TCD-D3 and TCD-D7 (sampling rate 48 kHz, 16 Bit dynamic range) connected to a Telinga Pro III parabolic stereo microphone (parabola diameter: 57 cm). Recently, we made some recordings also in the wider frequency range between 20 and 44000 Hz using Telinga Science Pro 5 with one of the microphones sensitive also in the ultrasonic range in connection with Pioneer DC-88 DAT in HS mode (sampling rate 96 kHz).

Sound recordings were transferred via the digital interface to an ADAP II- ATARI ST computer Hard Disk Recording system or through Digidesign Audiomedia III card into Pro Tools 3.21 and Sound Designer II programs on a PowerPC 8500/120 computer. There the recordings were visualized as oscillograms for selection of suitable sequences for analyses.

The temporal parameters were measured mainly with a multimedia-equipped IBM compatible personal computer (sound card with sampling rate 44.1 kHz, 16 Bit dynamic range) with analog input and output. Sound recordings were visualized as waveform with one of the two audio editors: Cool Edit 96 (Syntrillium) or Sound Forge 4.0 (Sonic Foundry). Recordings longer than 30 seconds were analyzed and selected parts were chosen for spectral analyses. Spectrograms and sonograms were made with Macintosh PowerPC using Canary 1.2 software.

Macro photographs were made with a Wild M8 stereo microscope with Photoautomat.

The Excel 97 program was used for statistical evaluation and graphic representation of temporal parameters.

## Results

The calling song of this species contains phrases of two types:

**Phrase type 1** consists of a long echeme (LE1) followed by a series of short echemes (SE1)(Fig. 3a). Such phrases are usually repeated periodically for some minutes.

During song production, one working cycle of a tymbal produces two short (0.6 - 1.0 ms) sound impulses with a repetition period of 2.3 - 2.5 ms ("in" and "out" clicks). Two tymbals alternate and the phase shift between them varies in the range of 0.8 - 1.3 ms. So one working cycle of both tymbals produces 4 clicks (Fig. 3c). All echemes in phrases of both types consist of these basic sound elements and differ only in their number (Fig. 3b,c and 7b,c). In the case of short echemes in phrase 1 tymbals work only once, giving just 4 clicks (Fig. 3b). In some recordings the amplitude of clicks produced by two tymbals is different (Fig. 3d). This difference can be so big that short echemes seem like double clicks as if only one tymbal was working. These differences in the amplitude of clicks are probably caused by directionality of tymbal sound emission and asymmetrical position of the microphone.

During emission of long echemes in phrases of both types, tymbals work with a rate of 140 - 200 Hz thus producing a continuous sequence of sound clicks with a mean repetition rate of 600 - 800 Hz. In most of these cases the groups of four clicks still can be clearly seen (Figs. 3b and 7b).

The mean duration of the long echemes measured in 6 animals, recorded in the narrow range of ambient temperature (30 - 33°C) is about 175 ms (from 80 to 290 ms) (Fig. 4a). Temporal parameters in the song of this species are temperature dependent (Fig. 5a,c). That is why the distribution of LE1 measured in the songs of 15 animals, recorded in the wide range of temperature (27 - 35°C) have a much more complex form (Fig. 5b), whereas the distribution of this parameter in single animals is always monomodal.

The mean repetition period of LE1 (= of phrases I) is 353 ± 51 ms (repetition rate is 2.8 Hz). There is a correlation between both parameters mentioned above despite of individual differences (Fig. 4b). The background of this phenomenon is a fairly stable interval between long echemes (Fig. 4c) despite of variability of LE1 duration. There is practically no correlation between LE1 duration and intervals between them (Fig. 4d).

The number of short echemes (SE1) varies from 1 to 6 and is in most cases 2 - 4 (Fig. 5d). In some occasions the short echemes are absent. The SE1 duration is 5.4 ± 1.7 ms. Temporal distribution of SE1 filling the gaps between long echemes is not linear and follows a certain order as one can see from Fig. 3a,b and the analysis of corresponding intervals (Fig. 6). The first interval after the LEI is usually about 50 ms (Fig. 6a,b). The following interval between the first and the second SE1 is nearly twice as long and the next intervals gradually decrease (Fig. 6a,c,d).

**Phrases type 2** are emitted less often and for a shorter period of time. The animals switch from emission of phrases type 1 to phrases type 2 or vice versa without any interruption. Sometimes elements of phrase 1 appear in some phrases of type 2. Each phrase 2 also contains one long echeme (LE2) followed usually by only one short echeme (SE2). One third of phrases type 2 does not contain any short echemes at all (Fig. 7a). LE2 and especially SE2 are much longer (273 ± 41 ms and 60 ± 6 ms rsp., Fig. 8a,c.) than corresponding parameters of phrases 1. The interval between long echemes is practically the same in both phrases (Fig. 8b, 4c). The mean interval between LE2 and SE2 is 32 ± 18 ms (Fig. 8d).

The spectral characteristics of both phrases are given in Figs. 9 and 10. It can be seen that most energy is concentrated in the range between 14 and 22 kHz with highest values between 16 - 20 kHz. Effective frequency range of these sounds, measured with the ultrasonic equipment (HS DAT, see above), does not exceed 25 to 30 kHz (e.g. Fig 9a,b). Therefore, for the detection of these cicadas in the field the heterodyne bat detectors should be tuned to the lowest ultrasonic range. Additional low frequency peak around 8 kHz (7  10 kHz) is better expressed in recordings made close to the singing male (Fig. 9).

## Discussion

In the introduction it was mentioned that the sounds of *Tettigetta brullei* recorded by us and sounds of *T. pygmea* described by Boulard (1995) are very similar. Our recordings were also compared with those by Boulard, represented on the CD, which accompanies the book by Boulard & Mondon (1995, track No. 20). It appears that there are practically no differences between the calling song of *T. pygmea* and the phrase type 1 of the calling song of *T. brullei.* Of course, this comparison might be superficial, because in the description published by Boulard (1995) only one example is presented without any statistical data. Nevertheless, the morphology and a comparison of song structure support the assumption that both taxa are synonyms.

If we compare the calling songs of related species of palaearctic Cicadettini (Popov 1997, Gogala et al. 1996, Gogala et al. 1997), a similarity in general organization of the songs is evident. In all the cases the calling song contains repeating phrases of two types, and each phrase is usually a certain combination of long and/or short echemes. Although the temporal pattern of the whole song is species specific and easily recognizable by humans, one of the phrases can be very similar in two or three species. Such examples are the type 1 phrases of *Cicadetta mediterranea* and *C. tibialis* or type 1 phrases of *Tettigetta brullei* and *Cicadetta popovi* (Popov 1997). In all these cases the second types of phrases are completely different. The frequency spectra in all these species are very similar but in *T. brullei* shifted to the higher frequencies extending into the ultrasonic range.

The temperature dependence of temporal parameters in the calling song of *T. brullei* causes difficulties in their statistical evaluation. Pooling together of data from recordings obtained at different ambient temperatures usually results in complicated multimodal distributions. In this case the mean values do not characterize sufficiently the parameters under study. Examples are given in this paper (compare Fig. 4a with 5b).

The paper describing the sounds of *Cicadetta tibialis* (Gogala et al. 1996) reports that most of temporal parameters are relatively independent of temperature. This conclusion was made after analyses of field recordings in different biotopes, although in laboratory conditions, where animals of the same species were exposed to rapid temperature changes, temporal parameters appeared to be strongly dependent on temperature (M. Petkovšek, unpublished data). Temperature independence found in the field could be the result of acclimatization to different environmental conditions, which might be an important mechanism for the conservation of species specific song patterns.

In the case of *T. brullei* all temporal parameters of the songs recorded in natural biotopes too, appeared to be temperature dependent. This might be evidence of another strategy for tuning sound reception to sound production, known in some other insects (Huber et al., 1989). In the first case the signal is stabilized despite of different environmental conditions and receivers should have a fixed template of a signal. In the second case both the properties of the signal and the selectivity of behavioral response change with temperature in parallel. Of all temporal parameters studied in the song of *Tettigetta brullei,* the interval between long echemes (with all short echemes included) seems to be the most stable and similar in both types of phrases. Therefore, it could be an important informative parameter for song recognition in intraspecific and interspecific communication.


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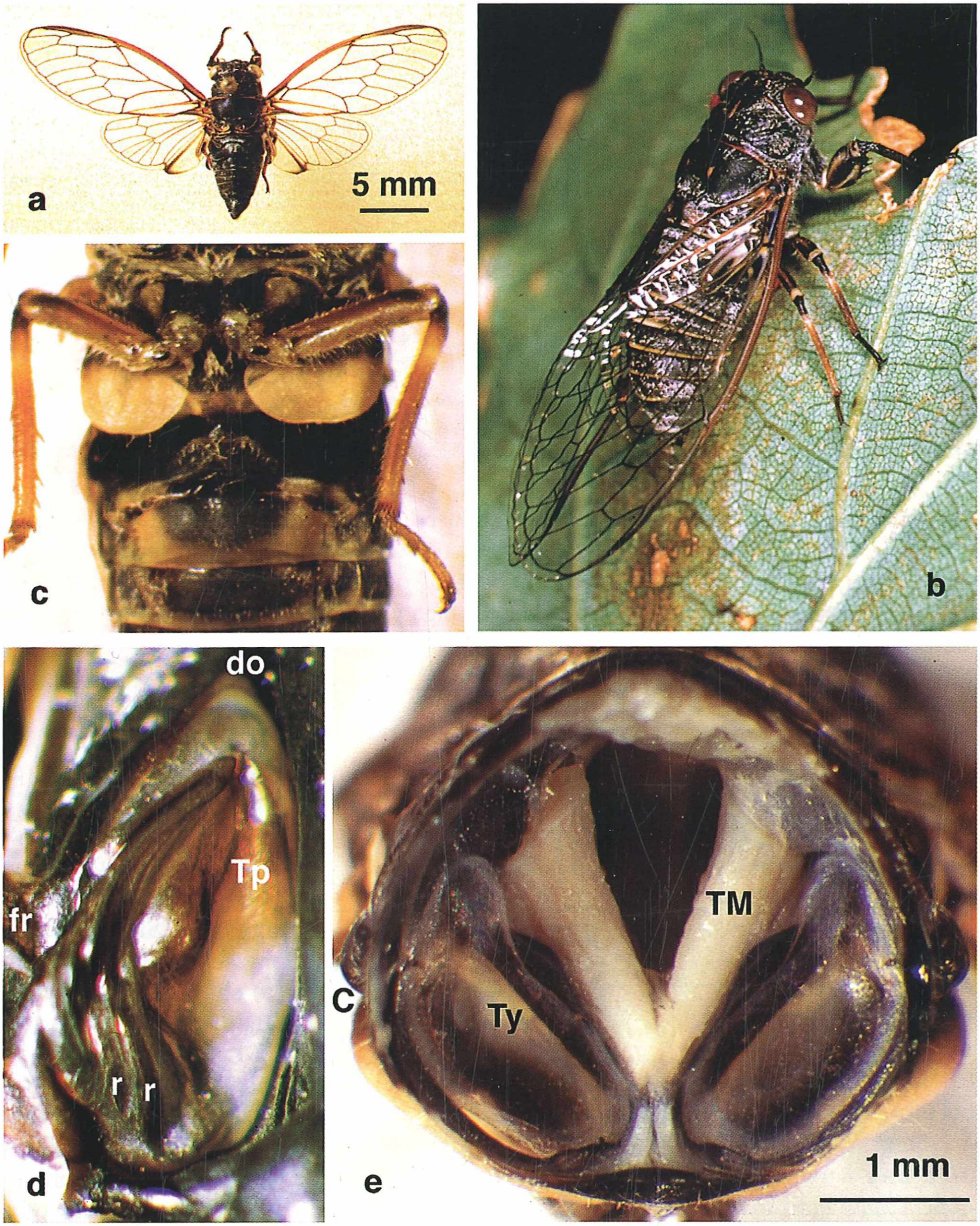


**Fig. 1:** ***Tettigetta brullei***, male a) specimen from the collection, b) male sitting on an oak leaf, c) ventral view with opercula, d) left tymbal with two long ribs (r) on the proximal field (do = dorsal, fr = frontal), e) tympanal membranes (Ty) and tymbal muscles (TM) - as seen caudally after the abdomen was removed (C = auditory capsule).


**Fig. 2:** A recordist with ultrasonic equipment used in the field survey of *T. brullei*. Left: TLG - Telinga parabola with ultrasonic microphone, DAT - digital tape recorder, USD - ultrasonic ("bat") detector; right: details of the attachment of the ultrasonic microphone in the reverse position to the Telinga parabola, in the background the bat detector S-25, Ultra Sound Advice.

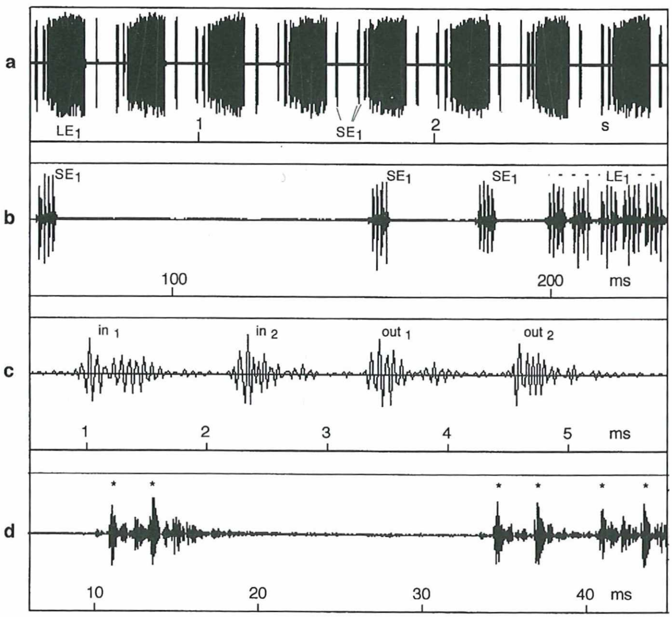


**Fig. 3:** Calling song, phrase 1: a) sample showing temporal structure with 1 long echeme (LE1) and 3 - 4 short echemes (SE1) in each phrase; b) selection from (a) showing a four-click structure in SE1 and LE1; c) oscillogram of one short echeme representing with high probability in and out clicks (in, out) of both tymbals (1, 2); d) example of a recording where signals from one tymbal (*) dominate in SE1 and LE1 (Sound Designer II).

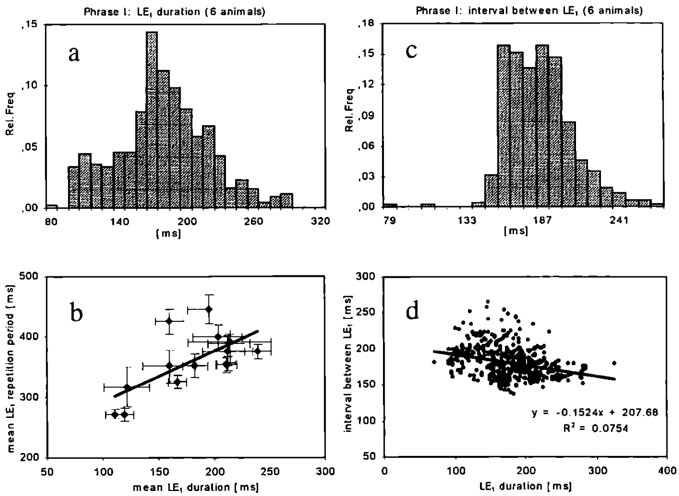


**Fig. 4:** Phrase 1 - histograms of temporal parameters and correlation between these values: a) LE1 duration; b) correlation between mean LE1 repetition period and mean LE1 duration - standard deviations bars are shown; c) interval between LE1; d) correlation of intervals between LE1 and LE1 duration (a,c,d - 6 selected animals, see text, b - 15 animals).

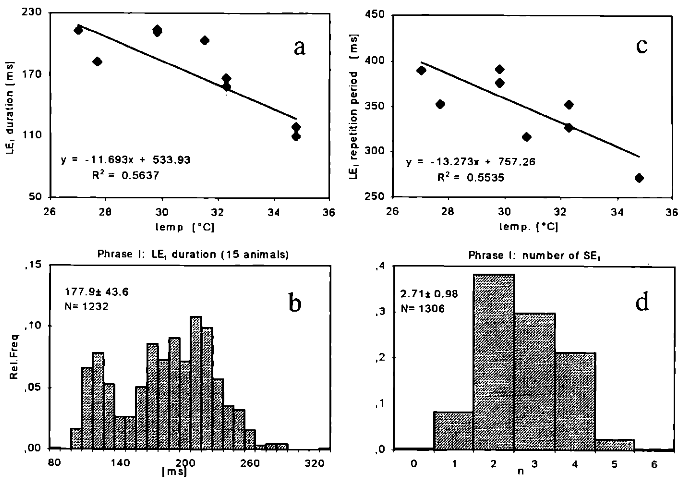


**Fig. 5:** Phrase 1 - temperature dependency (a-c) and phrase structure (d): a) LE1 duration in relation to temperature); b) Histogram showing multimodal distribution of LE1 duration recorded in 15 animals in a wide range of ambient temperatures (for details see text); c) LE1 repetition period in relation to temperature (for a and c 10 recordings were selected, where ambient temperature was exactly known) d) number of SE1 in a phrase (15 animals).

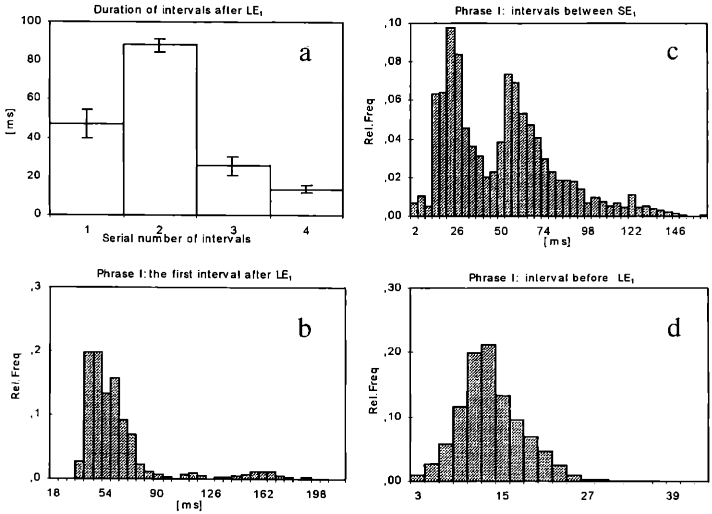


**Fig. 6:** Phrase I - histograms of temporal parameters: a) typical duration of subsequent intervals between echemes with 3 SE1 in a phrase (song of 1 specimen); b) duration of the first interval following LE1 and preceding the first SE1 in a phrase; c) distribution of all intervals between SE1; d) duration of the last interval in a phrase following the last SE1 and preceding the next LE1. (b,c,d - 15 animals)

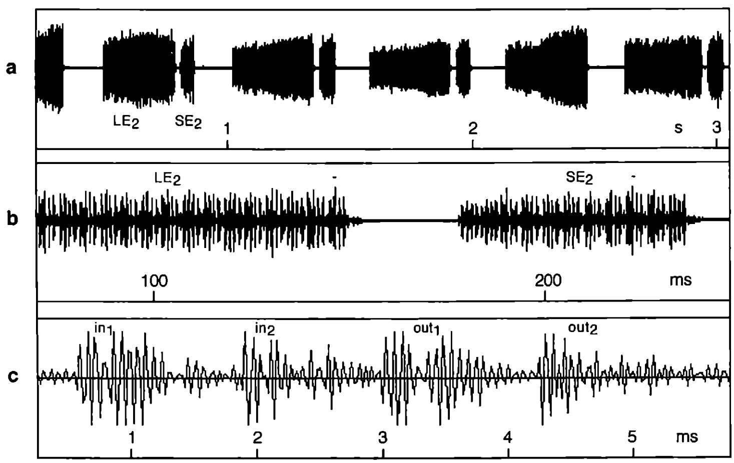


**Fig. 7:** Phrase 2 - a) sample showing temporal structure with 1 long echeme (LE2) and typically 1 short echeme (SE2) in each phrase; b) selection from (a) showing four click structure in LE2 and SE2; c) oscillogram of one four-click unit in SE2 representing with high probability in and out clicks (in, out) of both tymbals (1, 2) (Sound Designer II).

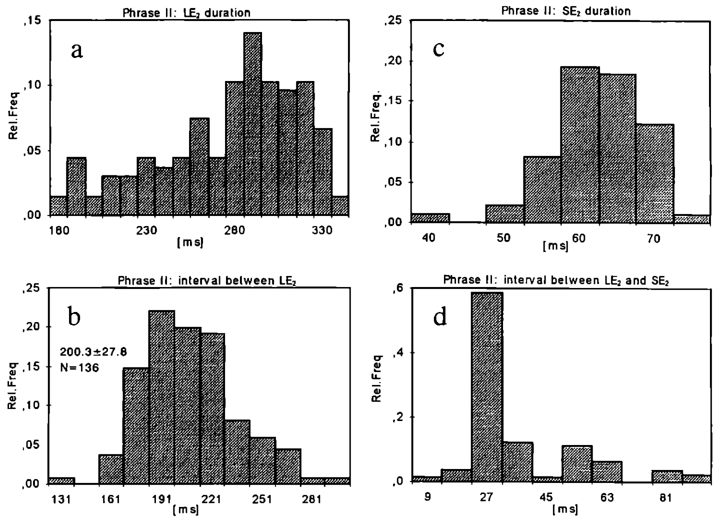


**Fig. 8:** Phrase 2 - histograms of temporal parameters: a) LE2 duration, b) duration of intervals between LE2, c) duration of SE2; d) interval between LE2 and SE2.

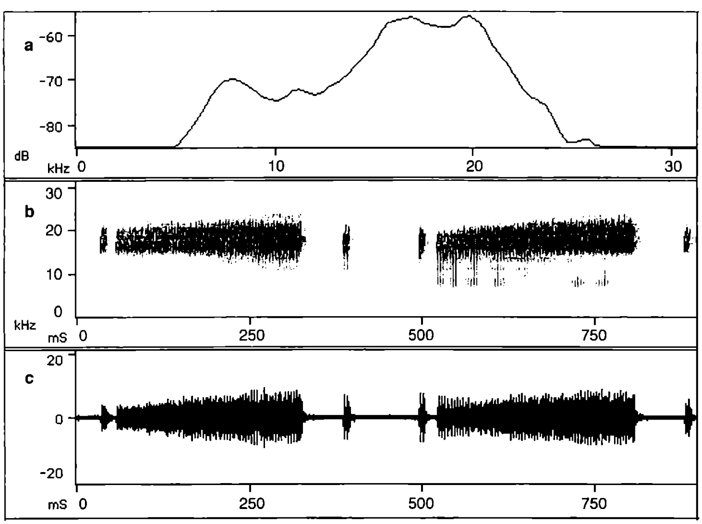


**Fig. 9:** Spectrogram (a), sonogram (b) and oscillogram (c) of a sequence of phrase 1. This recording was made with ultrasonic Telinga microphone and Pioneer DAT recorder in the HS mode (sample rate 96 kHz) (Canary 1.2).

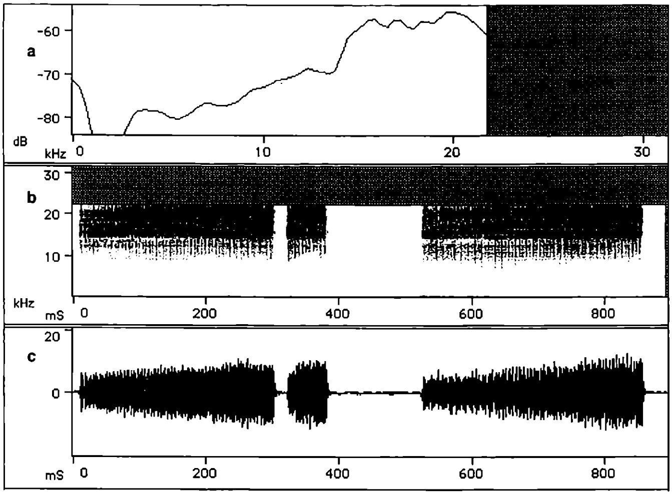


**Fig. 10:** Spectrogram (a), sonogram (b) and oscillogram (c) of a sequence of phrase 2 shown in the same scale as Fig. 9. This recording was made with Telinga microphone and Sony DAT recorder in the standard mode (sample rate 48 kHz), therefore the ultrasonic range can not be shown (Canary 1.2).

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