

RESEARCH NOTE

Open Access



High frequency audible calls in northern birch mice *Sicista betulina* in response to handling: effects of individuality, sex and body mass on the acoustics

Ilya A. Volodin^{1,2*} , Anna V. Klenova¹, Olga G. Ilchenko² and Elena V. Volodina²

Abstract

Objectives: This is the first study of the sonic and ultrasonic vocalization in a Dipodidae rodent. For the small-sized quadrupedal northern birch mouse *Sicista betulina*, phylogenetically related to the bipedal jerboas (Dipodidae), we report null results for ultrasonic vocalization and investigate the acoustic cues to individual identity, sex and body size in the discomfort-related high-frequency tonal sonic calls.

Results: We used a parallel audio recording in the sonic and ultrasonic ranges during weighting adult northern birch mice before the scheduled hibernation in captivity. The sonic (audible) high-frequency tonal calls (ranging from 6.21 to 9.86 kHz) were presented in all individuals (7 males and 4 females). The ultrasonic calls lacked in the recordings. Two-way nested ANOVA revealed the effects of caller individual identity on all 10 measured acoustic variables and the effects of sex on four out of 10 measured acoustic variables. Discriminant function analyses with 10 acoustic variables included in the analysis showed 85.5% correct assignment of calls to individual and 79.7% correct assignment of calls to sex; both values significantly exceeded the random values (23.1% and 54.3%, respectively) calculated with randomization procedure. Body mass did not differ between sexes and did not correlate significantly with the acoustic variables.

Keywords: Rodent, Distress calls, Acoustic communication, Ultrasonic vocalization, Emotional arousal, Birch mouse, Individuality, Body size, Sexual dimorphism, Dipodoidea

Introduction

Adult rodents may vocalize during handling in the lab [1–5]. These calls probably have no special function, being triggered by the elevated emotional arousal and discomfort of a caller [3, 4, 6–9]. Nevertheless, these calls may provide information about the caller, presented in the mammalian calls by default. Mammalian calls are offprints of individual vocal apparatus of a caller [10] and therefore by default provide information about caller's individual identity at level higher than by chance [11–17]. Call variables may provide general information

about body size [18, 19] and particular information about body mass [20] and body condition [21–24]. In addition, acoustic traits may reflect sexual dimorphism [14, 25–28].

Small mammals with their respectively small sound-producing structures commonly produce high-frequency sonic calls [29–31] along with ultrasonic calls above 20 kHz [32, 33]. Birch mice (genus *Sicista*, family Smithidae) are quadrupedal rodents, related to the bipedal jerboas Dipodidae and comprising together superfamily Dipodoidea. The northern birch mouse *Sicista betulina*, which status as a separate species was recently confirmed based on cytochrome *b* gene polymorphism [34], inhabit temperate forests and taiga from Western Europe to the Baikal region. This is a small mammal, with female body

*Correspondence: volodinsvoc@gmail.com

¹ Department of Vertebrate Zoology, Faculty of Biology, Lomonosov Moscow State University, Vorobievsky Gory, 1/12, Moscow 119234, Russia
Full list of author information is available at the end of the article



mass 9.4 ± 0.22 g and male body mass 8.98 ± 0.06 [35], maximum 10.4 g [36].

Northern birch mice are nocturnal but have bursts of activity during the day in spring and autumn [37] and hibernate for more than 7 months of the year [38]. There are no sustainable laboratory colonies of this species, as these animals poorly live in captivity, only for some months [37, 38]. At Moscow Zoo (Moscow, Russia), a temporal captive colony of northern birch mice emerged in 2018 from animals saved by volunteers during mass migration at peak of population growth, when many individuals were perishing in river water.

Calls of any Dipodoidea species have never been previously investigated. Zootechnical routine before the scheduled seasonal hibernation of small mammals at Moscow Zoo includes obligatory visual inspection and weighing of all individuals to estimate their body condition. Preliminary observations of the authors indicated that birch mice vocalize in human audible frequency range during this procedure. We expected that at handling, these small-sized rodents would vocalize in both the sonic and ultrasonic ranges, as e.g. laboratory rats [2] or some species of gerbils [4, 5]. In this study, we apply audio recording in both sonic and ultrasonic ranges of frequencies to record the discomfort-related calls of the captive northern birch mice. We describe the acoustic structure and estimate the effects of individuality, sex and body mass on the acoustic variables of these calls.

Main text

Methods

Calls of 11 adult northern birch mice (7 males, 4 females) were recorded from 12 to 17 September 2018 from members of a newly established captive colony of this species at Moscow Zoo (Moscow, Russia). All subjects were wild-captured in August 2018 on the eastern shore of the Yenisei River (Siberia, Russia) near the village Mirnoye ($62^{\circ}18'N$ $89^{\circ}01'E$).

The animals were kept under a natural light regime at temperature around $20^{\circ}C$, singly in wire-and-plastic cages of $40 \times 30 \times 30$ cm, with a bedding of mulch, soil, sand and enrichment of various shelters. They received custom-made small rodent chow with insect and mineral supplements and water ad libitum.

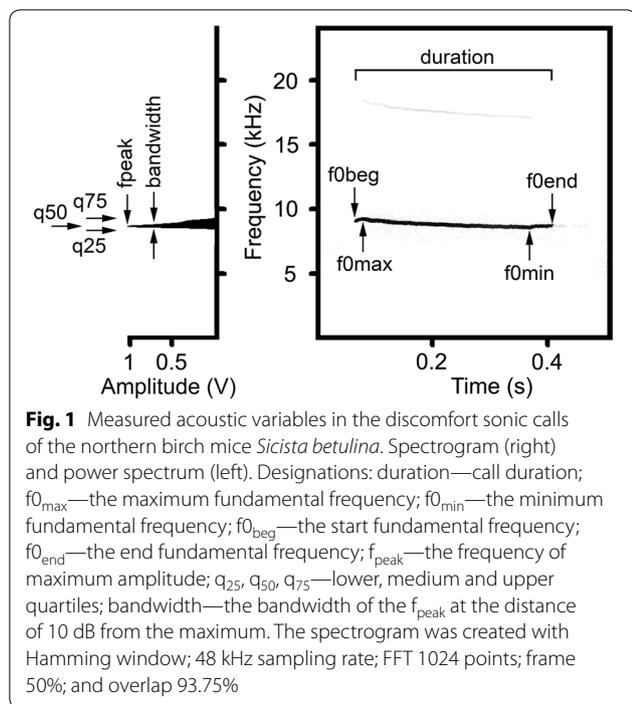
Calls of each animal were recorded during handling in daytime at temperature about $20^{\circ}C$. Parallel 1–2-min recording in the sonic (20 Hz–20 kHz) and ultrasonic (over 20 kHz) ranges of frequencies was conducted during the 1–2-min inspection-and-weighing procedure for preparing the animal to the scheduled hibernation. During the procedure, the animal was taken out of the home cage with a keeper hand, inspected

visually, weighed on the electronic scales G&G TS-100 (G&G GmbH, Neuss, Germany) with 0.01 g precision and returned back to the cage. During recording, a researcher could always clearly see that calls were emitted by a focal animal. Animal disturbance was kept at minimum; no special actions provoking vocalization was applied.

For the sonic recording (sampling rate 48 kHz, 16 bit resolution) we used a Marantz PMD-660 solid state recorder (D&M Professional, Kanagawa, Japan) with Sennheiser K6-ME64 microphone (Sennheiser electronic, Wedemark, Germany), hand-held at distance 0.5–1 m from the animal. For the ultrasonic recordings (254 kHz, 16 bit resolution), we used an Echo Meter Touch 2Pro (Wildlife Acoustics Inc., Maynard, MA, USA) run at Android smartphone OnePlus 3 (OnePlus Company, BBK Electronics LTD, Shenzhen, Guangdong, China), hand-held at distance 0.5–1 m from the animal.

Each recording trial provided two simultaneously recorded wav-files of the same length per individual, one sonic and one ultrasonic. In total, 17 recording trials (one trial per individual for five subjects and two trials per individual separated with time spans of 2–5 days for six subjects), provided in total 34 (17 sonic and 17 ultrasonic) wav-files for spectrographic analysis. For subjects with two trials per individual, weighting data were averaged for analyses.

Visual inspection of spectrograms of the wav-files using Avisoft SASLab Pro software (Avisoft Bioacoustics, Berlin, Germany) showed null results for presence of the ultrasonic calls, whereas all the sonic wav-files contained the same type of tonal high-frequency sonic calls. For acoustic analyses, we selected up to 20 (14–20) calls with good noise-to-call ratio per individual, 207 calls in total (Additional file 1: Table S1). If two recordings per animal were available, we selected calls in a balanced manner from both recordings. In each call, we measured 10 acoustic variables (Fig. 1). We measured, in the spectrogram window of Avisoft (sampling frequency 48 kHz, Hamming window, FFT 1024 points, frame 50%, overlap 96.87%, providing frequency resolution 47 Hz and time resolution 0.67 ms), call duration with the standard marker cursor, and the maximum fundamental frequency ($f_{0_{max}}$), the minimum fundamental frequency ($f_{0_{min}}$), the start fundamental frequency ($f_{0_{beg}}$) and the end fundamental frequency ($f_{0_{end}}$) with the reticule cursor. In each call, we also measured, in the power spectrum window of Avisoft, the frequency of maximum amplitude (f_{peak}), the three quartiles (q_{25} , q_{50} and q_{75}) covering, respectively 25%, 50% and 75% of call energy from the call's mean power spectrum, and the bandwidth of the f_{peak} at the distance of 10 dB from the maximum (Fig. 1). All



measurements were exported to Microsoft Excel (Microsoft Corp., Redmond, WA, USA).

Statistical analyses were made with STATISTICA, v. 8.0 (StatSoft, Tulsa, OK, USA); all means are given as mean \pm SD, and differences were considered significant whenever $p < 0.05$. Only three of the 110 distributions departed from normality (Kolmogorov–Smirnov test,

$p > 0.05$). We used two-way nested ANOVA with individual nested within sex, sex as fixed factor and individual as random factor, to estimate the effects of individuality and sex on the acoustic variables. We used one-way ANOVA to compare body mass between sexes. We used Pearson correlation with logarithm of body mass as proxy of body size to estimate effects of body size on the acoustic variables. We used discriminant function analysis (DFA) standard procedure to estimate potential for encoding individuality and sex by the high-frequency sonic calls of the northern birch mice. We used all 10 acoustic variables because they weakly correlated to each other on the basis of cross-correlation analysis, thus meeting the assumptions of DFA. The relative contribution of each acoustic variable in the correct assignment of calls to individual was estimated based on Wilks’ Lambda values, the smaller is the value, the greater is the contribution of the given acoustic variable to the overall discrimination [39].

Random values (of correct assignment to individual or to sex by chance) were calculated using randomization procedure [40] in R (<https://www.r-project.org>). The random values were averaged from DFAs performed on 1000 randomized permutations on the data sets, as in [39, 41].

Results

We did not find the ultrasonic calls in the studied northern birch mice during the handling procedures. The found sonic calls were rather long (from 0.24 to 0.65 s in different individuals) and high-frequency. Between individuals, the $f_{0_{min}}$ ranged from 6.21 to 8.69 kHz, the $f_{0_{max}}$

Table 1 Values of measured variables and their relationships with birch mouse sex, individuality and body mass

Variable	Mean \pm SD value			ANOVA		Pearson correlation with log body mass
	All animal calls	Male calls	Female calls	Sex	Individual identity	
Duration (s)	0.46 \pm 0.17	0.42 \pm 0.17	0.54 \pm 0.15	$F_{1,196} = 39.7; p < 0.001$	$F_{9,196} = 22.8; p < 0.001$	$r = 0.29; p = 0.42$
$f_{0_{max}}$ (kHz)	8.81 \pm 0.61	8.83 \pm 0.63	8.78 \pm 0.57	$F_{1,196} = 0.08; p = 0.78$	$F_{9,196} = 67.8; p < 0.001$	$r = 0.18; p = 0.62$
$f_{0_{min}}$ (kHz)	7.61 \pm 0.75	7.79 \pm 0.55	7.31 \pm 0.94	$F_{1,196} = 65.6; p < 0.001$	$F_{9,196} = 82.5; p < 0.001$	$r = -0.05; p = 0.90$
$f_{0_{beg}}$ (kHz)	8.70 \pm 0.71	8.70 \pm 0.74	8.70 \pm 0.65	$F_{1,196} = 2.06; p = 0.15$	$F_{9,196} = 76.9; p < 0.001$	$r = 0.09; p = 0.80$
$f_{0_{end}}$ (kHz)	7.95 \pm 0.59	7.93 \pm 0.57	7.99 \pm 0.63	$F_{1,196} = 2.93; p = 0.09$	$F_{9,196} = 29.3; p < 0.001$	$r = 0.28; p = 0.43$
f_{peak} (kHz)	8.05 \pm 0.74	8.14 \pm 0.56	7.90 \pm 0.98	$F_{1,196} = 6.23; p = 0.01$	$F_{9,196} = 53.7; p < 0.001$	$r = -0.16; p = 0.65$
q_{25} (kHz)	7.92 \pm 0.67	8.02 \pm 0.56	7.75 \pm 0.81	$F_{1,196} = 16.3; p < 0.001$	$F_{9,196} = 68.3; p < 0.001$	$r = -0.06; p = 0.87$
q_{50} (kHz)	8.34 \pm 0.68	8.31 \pm 0.50	8.38 \pm 0.93	$F_{1,196} = 2.38; p = 0.12$	$F_{9,196} = 13.2; p < 0.001$	$r = -0.01; p = 0.99$
q_{75} (kHz)	9.40 \pm 1.72	8.87 \pm 0.65	10.33 \pm 2.47	$F_{1,196} = 73.1; p < 0.001$	$F_{9,196} = 24.8; p < 0.001$	$r = -0.11; p = 0.75$
Bandwidth (kHz)	0.73 \pm 0.36	0.70 \pm 0.34	0.77 \pm 0.39	$F_{1,196} = 2.06; p = 0.15$	$F_{9,196} = 6.67; p < 0.001$	$r = -0.15; p = 0.67$
Body mass (g)	12.63 \pm 2.23	12.59 \pm 2.21	12.74 \pm 2.76	$F_{1,8} = 0.01; p = 0.93$		

Designations: duration—call duration; $f_{0_{max}}$ —the maximum fundamental frequency; $f_{0_{min}}$ —the minimum fundamental frequency; $f_{0_{beg}}$ —the start fundamental frequency; $f_{0_{end}}$ —the end fundamental frequency; f_{peak} —the frequency of maximum amplitude; q_{25} , q_{50} , q_{75} —lower, medium and upper quartiles; bandwidth—the bandwidth of the f_{peak} at the distance of 10 dB from the maximum; p estimates less than 0.05 are shown in underline

ranged from 8.06 to 9.86 kHz (Table 1, Fig. 2, Additional files 1 and 2). A common pattern of frequency modulation was a steady decrease of frequency from call beginning to call end. The $f_{0_{\max}}$ coincided with $f_{0_{\text{beg}}}$ in 96 of 207 (46.4%) calls, and was located in the first quarter of call duration in the other 91 (44.0%) calls. The $f_{0_{\min}}$ coincided with $f_{0_{\text{end}}}$ in 80 (38.6%) calls, and was located in the last quarter of call duration in the other 92 (44.4%) calls. The values of f_{peak} were always in the range of the fundamental frequency band. The fundamental frequency band was the band with most energy in all calls without exclusion. In some individuals, the fundamental frequency increased again at the end of a call, what in 17 (8.2%) calls resulted in the coincidence of the $f_{0_{\text{end}}}$ and $f_{0_{\max}}$ values (Fig. 2). Only four calls of one individual female contained nonlinear phenomena. Therefore, the high-frequency tonal calls of the northern birch mice had a very simple acoustic structure.

Two-way nested ANOVA revealed the effect of caller individual identity on all measured acoustic variables and the effect of sex on duration, $f_{0_{\min}}$, f_{peak} , q_{25} and q_{75} (Table 1). DFA showed 85.5% correct assignment of discomfort calls to individual, significantly exceeding the random value $23.1 \pm 2.4\%$ (permutation test, $p < 0.001$), and 79.7% correct assignment to sex, significantly exceeding the random value $54.3 \pm 2.8\%$ (permutation test, $p < 0.001$) (Fig. 2). The three acoustic variables that mainly contributed to discrimination to individual (in order of decreasing importance) were $f_{0_{\text{beg}}}$, $f_{0_{\max}}$ and duration, and those that mainly contributed to discrimination to sex were $f_{0_{\min}}$, $f_{0_{\text{end}}}$ and f_{peak} . Body mass did not differ between sexes and did not significantly correlate with acoustic variables (Table 1).

Discussion

This first study of vocalization in a Dipodidae rodent revealed that, in response to handling, adult northern birch mice of both sexes produced tonal calls of about 8–9 kHz (Fig. 2, Additional file 2). For presence of ultrasonic calls, we obtained negative results. The lack of ultrasonic calls was unexpected for such small mammal

(lighter than 10 g [35] or about 12 g in this study, Table 1). Nevertheless, for some other small mammals, as shrews, convincing negative results also indicate the absence of ultrasonic calls [42, 43].

In the northern birch mice, we found the lack of sexual dimorphism in body size, corresponding to only a weak sexual dimorphism in the acoustic variables. At the same time, their calls of very simple acoustic structure provided strong cues to acoustic individuality. Similar data regarding the lack of sexual dimorphism in body size, similar acoustics between sexes and high potential of high-frequency tonal calls to encode caller's individual identity in spite of their very simple acoustic structure, were obtained for the alarm calls of speckled ground squirrels *Spermophilus suslicus* [11, 13].

The study colony of Moscow Zoo consisted of wild-captured animals. Therefore, the collected acoustic material is valuable as reference data on vocalization, which was not yet affected by domestication, for comparison with data of further studies from colonies of birch mice in zoos and laboratories. In mammals kept in captivity for many generations, vocalization can be thoroughly changed compared to the founders [44, 45].

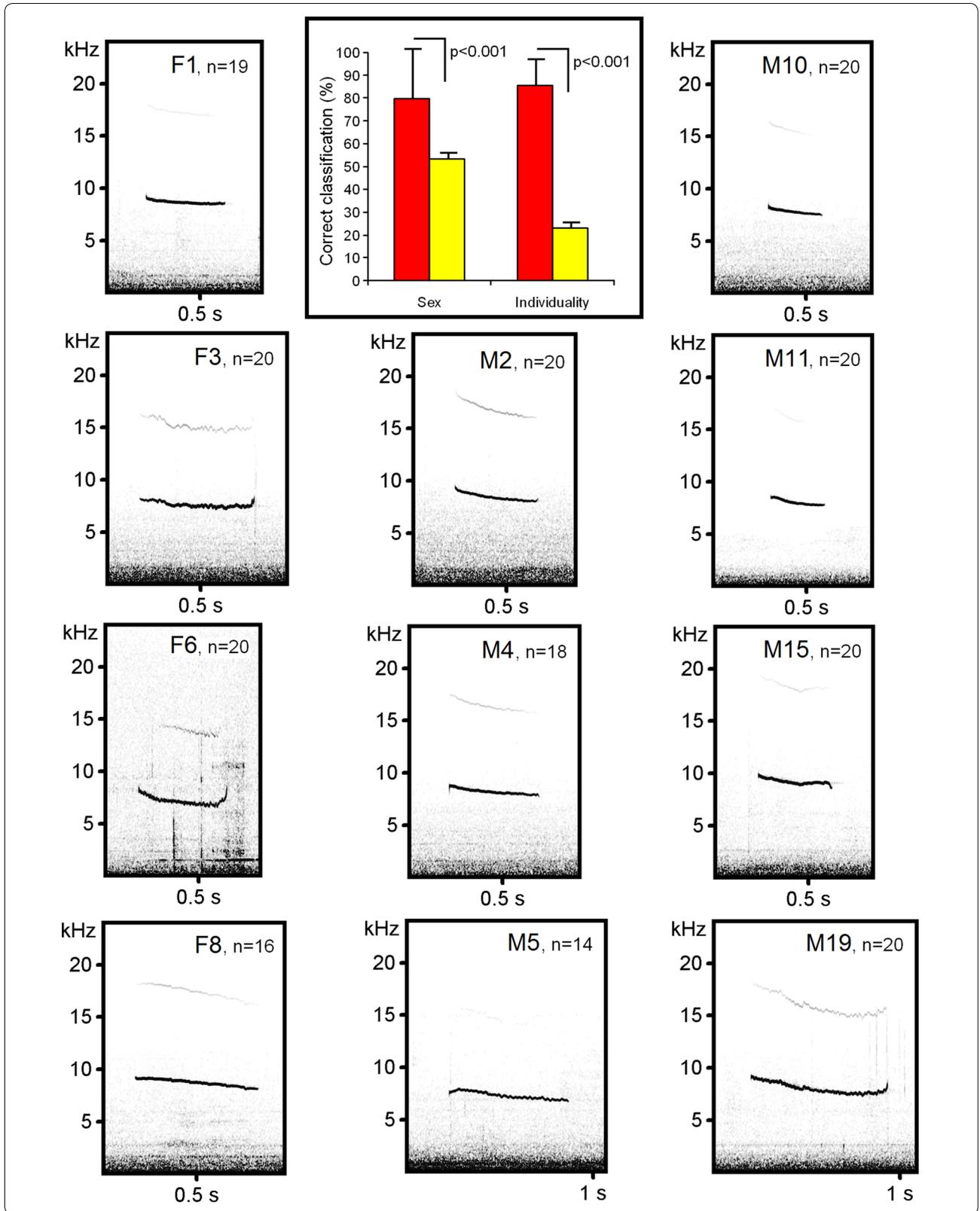
Limitations

This pilot study had a few limitations:

- The study was conducted in one lab in one newly established population, on a limited number of individuals, what limits expansion of results for the entire species.
- Recordings were made within a short period of a few days and in one behavioural context (handling-related discomfort), therefore the detected absence of ultrasonic calls in this species requires confirmation for other behavioral contexts.
- Precise age of the study animals was unknown. They could be young, old, or individuals of different ages, so the potential age-related acoustic variation could affect vocal variables.

(See figure on next page.)

Fig. 2 Individual and sexual identity in the discomfort sonic calls of the northern birch mice. Spectrograms of one call per individual are given for the 4 female (F1–F6) and 7 male (M2–M19) subject northern birch mice, n indicates the number of calls. Red bars represent the actual values of correct classifying of the discomfort calls to sex and to individual with DFA. Yellow bars represent the random (chance) values of correct classifying of the discomfort calls to sex and to individual with DFA. Comparisons between the actual and random values (indicated with brackets above the bars) were done using the permutation test. Bars indicate averages, whiskers indicate SD. The spectrogram was created with Hamming window; 48 kHz sampling rate; FFT 1024 points; frame 50%; and overlap 87.5%. Original wav-files are available in Additional file 2



Supplementary information

Supplementary information accompanies this paper at <https://doi.org/10.1186/s13104-019-4719-9>.

Additional file 1: Table S1. Data table with body mass and acoustic measurements of discomfort-related sonic calls of the study northern birch mice. **Additional file 2: Audio S1.** Audio wav-file with discomfort-related sonic calls of 4 female and 7 male northern birch mice *Sicista betulina*, two calls per individual are given.

Abbreviations

DFA: discriminant function analysis; $f_{0_{max}}$: the maximum fundamental frequency; $f_{0_{min}}$: the minimum fundamental frequency; $f_{0_{beg}}$: the start fundamental frequency; $f_{0_{end}}$: the end fundamental frequency; f_{peak} : call maximum amplitude frequency; q_{25} : call lower power quartile; q_{50} : call medium power quartile; q_{75} : call upper power quartile.

Acknowledgements

We are grateful to the staff of Moscow Zoo for their help and support.

Authors' contributions

IAV and EVV proposed the idea of the study. IAV and EVV secured funding. IAV and OGI collected data. AVK conducted the bioacoustical and statistical analyses. EVV, IAV and AVK provided scientific input for the study design and prepared the manuscript draft. All authors reviewed/commented the draft. All authors read and approved the final manuscript.

Funding

This study was supported by Russian Science Foundation (<http://www.rscf.ru/>), Grant Number 19-14-00037 to IAV, AVK and EVV. The funder had no role in the design of the study and data collection, analysis and interpretation of data and in writing the manuscript.

Availability of data and materials

The dataset supporting the conclusions of this article is included within the article and its additional files.

Ethics approval and consent to participate

This study was the part of the research program of the Scientific Research Department of Moscow Zoo. Three authors, who collected material, are zoo staff members, so no special permission was required for them to work with animals in Moscow Zoo. All study animals belonged to the laboratory collection of Moscow Zoo. The experimental procedure has been approved by the Committee of Bio-ethics of Lomonosov Moscow State University, research protocol # 2011-36. We adhered to the 'Guidelines for the treatment of animals in behavioural research and teaching' (Anim. Behav., 2006, 71, 245–253) and to the laws on animal welfare for scientific research of the Russian Federation, where the study was conducted. No one single animal suffered due to data collection.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

Author details

¹ Department of Vertebrate Zoology, Faculty of Biology, Lomonosov Moscow State University, Vorobievsky Gory, 1/12, Moscow 119234, Russia. ² Scientific Research Department, Moscow Zoo, B. Gruzinskaya, 1, Moscow 123242, Russia.

Received: 29 May 2019 Accepted: 10 October 2019

Published online: 22 October 2019

References

- Houseknecht CR. Sonographic analysis of vocalizations of three species of mice. *J Mammal.* 1968;49:555–60. <https://doi.org/10.2307/1378232>.
- Brudzynski SM, Ociepa D. Ultrasonic vocalization of laboratory rats in response to handling and touch. *Physiol Behav.* 1992;52:655–60. [https://doi.org/10.1016/0031-9384\(92\)90393-G](https://doi.org/10.1016/0031-9384(92)90393-G).
- Grimsley JMS, Sheth S, Vallabh N, Grimsley CA, Bhattal J, Latsko M, Jasnow A, Wenstrup JJ. Contextual modulation of vocal behavior in mouse: newly identified 12 kHz "mid-frequency" vocalization emitted during restraint. *Front Behav Neurosci.* 2016;10:38. <https://doi.org/10.3389/fnbeh.2016.00038>.
- Zaytseva AS, Volodin IA, Ilchenko OG, Volodina EV. Discomfort-related changes in pup ultrasonic calls of fat-tailed gerbils *Pachyuromys duprasi*. *Bioacoustics.* 2017;26:1–13. <https://doi.org/10.1080/09524622.2016.1164076>.
- Zaytseva AS, Volodin IA, Ilchenko OG, Volodina EV. Ultrasonic vocalization of pup and adult fat-tailed gerbils (*Pachyuromys duprasi*). *PLoS ONE.* 2019;14(7):e0219749. <https://doi.org/10.1371/journal.pone.0219749>.
- Brudzynski SM. Ethotransmission: communication of emotional states through ultrasonic vocalization in rats. *Curr Opin Neurobiol.* 2013;23:310–7. <https://doi.org/10.1016/j.conb.2013.01.014>.
- Brudzynski SM. Pharmacology of ultrasonic vocalizations in adult rats: significance, call classification and neural substrate. *Curr Neuropharmacol.* 2015;13:180–92. <https://doi.org/10.2174/1570159X13999150210141444>.
- Wöhr M, Schwarting RK. Affective communication in rodents: ultrasonic vocalizations as a tool for research on emotion and motivation. *Cell Tissue Res.* 2013;354:81–97. <https://doi.org/10.1007/s00441-013-1607-9>.
- Volodin IA, Volodina EV, Frey R, Kirilyuk VE, Naidenko SV. Unusually high-pitched neonate distress calls of the open-habitat Mongolian gazelle (*Procapra gutturosa*) and their anatomical and hormonal predictors. *Sci Nat.* 2017;104:50. <https://doi.org/10.1007/s00114-017-1471-7>.
- Gamba M, Favaro L, Araldi A, Matteucci V, Giacoma C, Friard O. Modeling individual vocal differences in group-living lemurs using vocal tract morphology. *Curr Zool.* 2017;63:467–75. <https://doi.org/10.1093/cz/zox003>.
- Matrosova VA, Volodin IA, Volodina EV. The short-term and long-term individuality in speckled ground squirrel alarm calls. *J Mammal.* 2009;90:158–66. <https://doi.org/10.1644/08-MAMM-A-032.1>.
- Matrosova VA, Volodin IA, Volodina EV, Vasilieva NA, Kochetkova AA. Between-year stability of individual alarm calls in the yellow ground squirrel *Spermophilus fulvus*. *J Mammal.* 2010;91:620–7. <https://doi.org/10.1644/09-MAMM-A-143.1>.
- Matrosova VA, Blumstein DT, Volodin IA, Volodina EV. The potential to encode sex, age, and individual identity in the alarm calls of three species of Marmotinae. *Naturwissenschaften.* 2011;98:181–92. <https://doi.org/10.1007/s00114-010-0757-9>.
- Moreno-Gómez FN, León A, Velasquez NA, Penna M, Delano PH. Individual and sex distinctiveness in bark calls of domestic chinchillas elicited in a distress context. *J Acoust Soc Am.* 2015;138:1614–22. <https://doi.org/10.1121/1.4929750>.
- Ancilotto L, Russo D. Individual vs. non-individual acoustic signaling in African woodland dormice (*Graphiurus murinus*). *Mammal Biol.* 2016;81:410–4. <https://doi.org/10.1016/j.mambio.2016.05.001>.
- Volodin IA, Sibiryakova OV, Frey R, Efremova KO, Soldatova NV, Zuther S, Kisebaev TB, Salemgareev AR, Volodina EV. Individuality of distress and discomfort calls in neonates with bass voices: wild-living goitred gazelles (*Gazella subgutturosa*) and saiga antelopes (*Saiga tatarica*). *Ethology.* 2017;123:386–96. <https://doi.org/10.1111/eth.12607>.
- Volodin IA, Matrosova VA, Frey R, Kozhevnikova JD, Isaeva IL, Volodina EV. Altai pika (*Ochotona alpina*) alarm calls: individual acoustic variation and the phenomenon of call-synchronous ear folding behavior. *Sci Nat.* 2018;105:40. <https://doi.org/10.1007/s00114-018-1567-8>.
- Charlton BD, Reby D. The evolution of acoustic size exaggeration in terrestrial mammals. *Nat Comm.* 2016;7:12739. <https://doi.org/10.1038/ncomms12739>.

19. Martin K, Tucker MA, Rogers TL. Does size matter? Examining the drivers of mammalian vocalizations. *Evolution*. 2017;71:249–60. <https://doi.org/10.1111/evo.13161>.
20. Yosida S, Kobayashi KI, Ikebuchi M, Ozaki R, Okanoya K. Antiphonal vocalization of a subterranean rodent, the naked mole-rat (*Heterocephalus glaber*). *Ethology*. 2007;113:703–10. <https://doi.org/10.1111/j.1439-0310.2007.01371.x>.
21. Wyman MT, Mooring MS, McCowan B, Penedo MCT, Hart LA. Amplitude of bison bellows reflects male quality, physical condition and motivation. *Anim Behav*. 2008;76:1625–39. <https://doi.org/10.1016/j.anbehav.2008.05.032>.
22. Smirnova DS, Volodin IA, Demina TS, Volodina EV. Acoustic structure and contextual use of calls by captive male and female cheetahs (*Acinonyx jubatus*). *PLoS ONE*. 2016;11(6):e0158546. <https://doi.org/10.1371/journal.pone.0158546>.
23. Burkhard TT, Westwick RR, Phelps SM. Adiposity signals predict vocal effort in Alston's singing mice. *Proc R Soc B*. 2018;285:20180090. <https://doi.org/10.1098/rspb.2018.0090>.
24. Volodin IA, Sibiryakova OV, Vasilieva NA, Volodina EV, Matrosova VA, Garcia AJ, Pérez-Barbería FJ, Gallego L, Landete-Castillejos T. Old and young female voices: effects of body weight, condition and social discomfort on the vocal aging in red deer hinds (*Cervus elaphus*). *Behaviour*. 2018;155:915–39. <https://doi.org/10.1163/1568539X-00003513>.
25. Holman SD. Sexually dimorphic, ultrasonic vocalizations of Mongolian gerbils. *Behav Neural Biol*. 1980;28:183–92. [https://doi.org/10.1016/S0163-1047\(80\)91535-6](https://doi.org/10.1016/S0163-1047(80)91535-6).
26. Holman SD, Seale WTC. Ontogeny of sexually dimorphic ultrasonic vocalizations in Mongolian gerbils. *Dev Psychobiol*. 1991;24:103–15. <https://doi.org/10.1002/dev.420240204>.
27. Fernández-Vargas M, Johnston RE. Ultrasonic vocalizations in golden hamsters (*Mesocricetus auratus*) reveal modest sex differences and nonlinear signals of sexual motivation. *PLoS ONE*. 2015;10(2):e0116789. <https://doi.org/10.1371/journal.pone.0116789>.
28. Zala SM, Reitschmidt D, Noll A, Balazs P, Penn DJ. Sex-dependent modulation of ultrasonic vocalizations in house mice (*Mus musculus musculus*). *PLoS ONE*. 2017;12(12):e0188647. <https://doi.org/10.1371/journal.pone.0188647>.
29. Riede T, York A, Furst S, Müller R, Seebeck S. Elasticity and stress relaxation of a very small vocal fold. *J Biomech*. 2011;44:1936–40. <https://doi.org/10.1016/j.jbiomech.2011.04.024>.
30. Riede T, Brown C. Body size, vocal fold length, and fundamental frequency—implications for mammal vocal communication. *Nova Acta Leopoldina NF*. 2013;111:295–314.
31. Titze I, Riede T, Mau T. Predicting achievable fundamental frequency ranges in vocalization across species. *PLoS Comput Biol*. 2016;12(6):e01004907. <https://doi.org/10.1371/journal.pcbi.1004907>.
32. Brudzynski SM. Social origin of vocal communication in rodents. In: Wit-zany G, editor. *Biocommunication of animals*. Dordrecht: Springer; 2014. p. 63–79. https://doi.org/10.1007/978-94-007-7414-8_5.
33. Brudzynski SM, Zeskind PS. Introduction and overview of the handbook of ultrasonic vocalization. In: Brudzynski SM, editor. *Handbook of ultrasonic vocalization*, V. 25: a window into the emotional brain. Amsterdam: Elsevier; 2018. p. 3–5. <https://doi.org/10.1016/b978-0-12-809600-0-00001-9>.
34. Lebedev VS, Rusin MY, Zemlemerova ED, Matrosova VA, Bannikova AA, Kovalskaya YM, Tesakov AS. Phylogeny and evolutionary history of birch mice *Sicista* Griffith, 1827 (Sminthidae, Rodentia): implications from a multigene study. *J Zool Syst Evol Res*. 2019;57:695–709. <https://doi.org/10.1111/jzs.12279>.
35. Kukhareva AV. The northern birch mouse (*Sicista betulina* Pall.) on the northern edge of distribution area. (Ph.D. thesis). Moscow: Moscow Pedagogical State University; 2010. p. 20.
36. Juskaitis R. New data on the birch mouse (*Sicista betulina*) in Lithuania. *Folia Theriol Estonica*. 2000;5:51–6.
37. Erkinaro E. Phase shift of locomotory activity in a Birch mouse, *Sicista betulina*, before hibernation. *J Zool*. 1972;168:433–8. <https://doi.org/10.1111/j.1469-7998.1972.tb01359.x>.
38. Johansen K, Krog J. Diurnal body temperature variations and hibernation in the birchmouse, *Sicista betulina*. *Am J Physiol*. 1959;196:1200–4. <https://doi.org/10.1152/ajplegacy.1959.196.6.1200>.
39. Sibiryakova OV, Volodin IA, Matrosova VA, Volodina EV, Garcia AJ, Gallego L, Landete-Castillejos T. The power of oral and nasal calls to discriminate individual mothers and offspring in red deer, *Cervus elaphus*. *Front Zool*. 2015;12:2. <https://doi.org/10.1186/s12983-014-0094-5>.
40. Solow AR. A randomization test for misclassification probability in discriminant analysis. *Ecology*. 1990;71:2379–82. <https://doi.org/10.2307/1938650>.
41. Volodin IA, Sibiryakova OV, Soldatova NV, Volodina EV. Acoustically different contact calls of mother and young goitred gazelle are equally individualized: is this a common relationship in ruminants? *Behaviour*. 2019;156:1185–207. <https://doi.org/10.1163/1568539X-00003561>.
42. Volodin IA, Zaytseva AS, Ilchenko OG, Volodina EV. Small mammals ignore common rules: a comparison of vocal repertoires and the acoustics between pup and adult piebald shrews *Diplomesodon pulchellum*. *Ethology*. 2015;121:103–15. <https://doi.org/10.1111/eth.12321>.
43. Zaytseva AS, Volodin IA, Mason MJ, Frey R, Fritsch G, Ilchenko OG, Volodina EV. Vocal development during postnatal growth and ear morphology in a shrew that generates seismic vibrations, *Diplomesodon pulchellum*. *Behav Process*. 2015;118:130–41. <https://doi.org/10.1016/j.beproc.2015.06.012>.
44. Monticelli PF, Ades C. Bioacoustics of domestication: alarm and courtship calls of wild and domestic cavies. *Bioacoustics*. 2011;20:169–92. <https://doi.org/10.1080/09524622.2011.9753642>.
45. Gogoleva SS, Volodin IA, Volodina EV, Kharlamova AV, Trut LN. Effects of selection for behavior, human approach mode and sex on vocalization in silver fox. *J Ethol*. 2013;31:95–100. <https://doi.org/10.1007/s10164-012-0353-x>.

Publisher's Note

Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Ready to submit your research? Choose BMC and benefit from:

- fast, convenient online submission
- thorough peer review by experienced researchers in your field
- rapid publication on acceptance
- support for research data, including large and complex data types
- gold Open Access which fosters wider collaboration and increased citations
- maximum visibility for your research: over 100M website views per year

At BMC, research is always in progress.

Learn more biomedcentral.com/submissions

