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Short Note

Seismic communication in spalacids: signals in the giant root-rat and Gansu zokor

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Abstract

We analysed seismic signals in two spalacid rodents with a different degree of fossoriality: the giant root-rat (*Tachyoryctes macrocephalus*) and the Gansu zokor (*Eospalax cansus*). As all hitherto studied spalacids they also produce seismic signals by head-thumping, which probably evolved as a ritualization of soil tampering. The seismic signal of giant root-rat contains 5.51±1.60 pulses with inter-pulse distance of 0.11±0.01 s. The Gansu zokors produce seismic signals with 6.90±2.33 pulses and inter-pulse distance of 0.13±0.01s. Both studied species produced seismic signals during the peak of activity, most likely as territorial advertisement. No relationship has been found between inter-pulse distance and body mass in studied spalacid species; although this relationship did appear when the giant root-rat, the largest and most fossorial species, was excluded from the analysis. The seismic signals in spalacids can be considered as species specific.

Seismic communication has been described in different animal taxa, including over 40 rodent species in 18 genera (Hill, 2008; Randall, 1993). This type of communication is advantageous especially in situations where traditional long-range communication channels are restricted, costly or jammed. In rodents, seismic signals are used mainly as territorial advertisement, anti-predatory signalling and for mating purposes (reviewed in Hill, 2008). This way of communication is common in two ecological groups of rodents. The first group comprises epigeic species living in sparsely vegetated desert areas. In such environments, seismic signals appear to be an effective way of signalling between distant individuals (Randall, 1994). The other group consists of rodents with a predominantly subterranean activity (Hill, 2008). For them, substrate-borne vibrations are the only effective means of long-distance communication, since the attenuation of airborne sound waves by the soil separating burrow systems makes vocalisation ineffective (e.g. Narins et al., 1992). Rodents have four ways of producing seismic signals. The most common is foot-thumping, occurring in epigeic species (Hill, 2008) and in some subterranean species (Jarvis and Bennett, 1991; Narins et al., 1992). Another is chest-beating, found in the giant mole-rat (*Fukomys mechowii*) (Bednářová et al., 2013). In two microtines, seismic signals are produced by incisor-tapping (Giannoni et al., 1997). Finally, spalacids use head-thumping, striking their head against the tunnel ceiling (Heth et al., 1987; Rado et al., 1987; Li et al., 2001; Hrouzková et al., 2013). A typical seismic signal consists of pulses (strikes of the particular body part against solid substrate), which can come together in bouts (sets of pulses) and may in turn further associate in series. The bouts may exhibit different pulse patterns, which can be species, sex, population, or individual specific (Narins et al., 1992; Randall, 1995, 1997). The thumping pattern in kangaroo rats (Dipododidae) and wood rats (*Neotoma* spp.) seems to be influenced by body weight. The largest species, weighing about 150 g, possess the most elaborated signals, with several foot-roll sequences, whereas medium-sized ones perform a rudimentary signal with only one foot-roll. Species weighing less than 60 g do not drum at all (Howe, 1978; Randall, 1997). The Spalacidae, a rodent family including blind mole rats, zokors, root-rats and bamboo rats, are extremely suitable for the study of seismic communication and how it relates to body mass and the degree of fossoriality, because both factors vary remarkably across species (Norris, 2017). We studied seismic signals in two spalacids differing in size and the degree of fossoriality under natural and laboratory conditions. The aim of the study was 1) to describe the physical parameters, behavioural context and daily pattern of these seismic signals, and 2) to confront the data collected with those on other spalacids described in the literature, in order to reveal if the physical characteristics of the signals are influenced by the species' body mass and level of fossoriality.

The giant root-rat (*Tachyoryctes macrocephalus*, Rüppell 1842) is a large fossorial species endemic to the Bale Mountains of Ethiopia (Norris, 2017). It comes regularly to the soil surface to collect food (Vlasatá et al., 2017). The research presented here was conducted in March 2014 in the Web Valley, Bale Mountains (6°59.5′ N, 39°42.1′ E, 3500 m a.s.l.). The Gansu zokor (*Eospalax cansus*, Milne-Edwards 1867) is a subterranean rodent distributed across grasslands and shrublands in Gansu, Ningxia, Sichuan and Hubei, China. It lives almost exclusively underground (Norris, 2017). The Gansu zokors were recorded near Tianzhu field station of the Gansu Agricultural University, Tianzhu Tibetan Autonomous County, Gansu, China (6°59.505′ N, 39°42.149′ E, 2900 m a.s.l.) during June and July 2015. The way of producing seismic signals was analysed in pairs of animals temporarily captured (Vlasatá et al., 2017; Hua et al., 2015), using a transparent artificial Perspex tunnel system with two home boxes connected by a

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Table 1 – Characteristics of seismic signals of spalacid rodents. Means ± SD are presented.

Species	Study type	N individuals (M:F)	Body mass (g)	Pulses per bout	Inter-pulse distance (s)	Bouts per series	Inter-bout distance (s)
Tachyoryctes macrocephalus[1]	Field	13(5:8)	777	5.51 ± 1.60	0.11 ± 0.01	2.9 ± 1.1	1.90 ± 0.90
male	Field	5(5:0)	858	5.70 ± 1.28	0.11 ± 0.01	3.0 ± 1.3	2.09 ± 0.93
female	Field	8(0:8)	672	5.21 ± 1.91	0.11 ± 0.01	2.00 ± 0.94	1.63 ± 0.72
Eospalax cansus[1]	Field	8(2:6)	190	6.90 ± 2.33	0.13 ± 0.01	3.80 ± 2.21	1.90 ± 0.86
male	Field	2(2:0)	195	6.21 ± 2.19	0.13 ± 0.01	6.00 ± 4.24	2.28 ± 1.37
female	Field	6(0:6)	183	7.11 ± 2.35	0.12 ± 0.01	3.46 ± 1.81	1.78 ± 0.63
Eospalax cansus (male)[2]	Laboratory	4(4:0)	195	4.74 ± 0.25	0.10 ± 0.01		
Eospalax cansus (female)[2]	Laboratory	4(0:4)	183	6.12 ± 0.29	0.11 ± 0.01		
Tachyoryctes splendens[3]	Laboratory	6(4:2)	170	9.53 ± 4.22	0.12 ± 0.02	17.79 ± 15.55	3.89 ± 6.27
Spalax galili[4]	Laboratory	24(22:2)	150	3.66 ± 1.40	0.10 ± 0.04	2.95 ± 2.03	1.06 ± 0.64
Spalax galili[5]	Laboratory	14(1:13)	124[7]	4.01 ± 0.56	0.09 ± 0.01	2.60 ± 0.77	0.79 ± 0.11
Spalax golali[5]	Laboratory	18(3:15)	143[7]	3.88 ± 0.31	0.08 ± 0.02	2.66 ± 0.47	0.96 ± 0.05
Spalax golali[6]	Laboratory	7(4:3)	159[7]	2.19 ± 0.52	0.14 ± 0.01		0.39 ± 0.18
Spalax carmeli[5]	Laboratory	6(3:3)	129[7]	4.05 ± 1.50	0.08 ± 0.01	3.04 ± 0.46	0.87 ± 0.08
Spalax carmeli[6]	Laboratory	6(5:1)	138[7]	4.06 ± 0.46	0.12 ± 0.01		0.44 ± 0.30
Spalax judaei[5]	Laboratory	15(8:7)	119[7]	6.05 ± 0.39	0.09 ± 0.01	2.27 ± 0.30	0.89 ± 0.08

[1] this study;
[2] Li et al. (2001);
[3] Hrouzková et al. (2013);
[4] our unpublished data;
[5] Heth et al. (1991);
[6] Heth et al. (1987);
[7] the weights were calculated with the respect to the sex ratio in particular studies, Nevo et al. (1986).

tunnel. Interactions of both homo- and heterosexual pairs were recorded for 10 minutes using a Panasonic SDR-H69 video camera. Seismic signals were recorded in field conditions using a Gaia 3r digital data acquisition system (Vistec, working range 20–500 Hz, sampling frequency 100 sps) with six seismometers ViGeo 5-1d (Vistec, sensitivity 290 V/m/s). The seismometers were placed on the surface in two lines above the burrows, 3 m from each other. All individuals were weighed and sexed before the recording. The positions of the burrow systems were known from a concurrent radio-tracking study, or alternatively estimated based on the distribution of molehills and sites of capture. Seismic signals were recorded from 09:00 to 19:00 in *T. macrocephalus*, and in irregular time intervals lasting 17:05±1:58 hours and covering a 24 h cycle in *E. cansus*. All recordings were processed by Seismic Waves Interpretation Programme (SWIP) version 3.2.4. Parameters were extracted manually, the pulse was taken as the highest peak in the oscillogram from the sensor with the highest amplitude response. Communication was considered antiphonal when at least two animals transmit vibrations in response to preceding signal (Yosida et al., 2007). Statistical analysis was performed using STATISTICA StatSoft, Inc (2013) version 12. The parameters of the seismic signals analysed were the inter-pulse distance (s), the number of pulses within each bout, and the distance between bouts (s). Sexual differences in *T. macrocephalus* signals were analysed by the Mann-Whitney U test. The influence of body mass on inter-pulse distance and number of pulses in seven spalacid species (Tab. 1) was analysed by linear regression. The analysis of specificity of seismic signalling was performed in species with sufficient datasets (*Spalax galili*, *E. cansus*, *T. macrocephalus*, *T. splendens*) by Discriminant Function Analysis (DFA) with a priori classification. Seismic signals of *S. galili* were collected in Kerem Ben Zimra, Israel during the year 2016. For details of seismic signals of *T. splendens*, see Hrouzková et al. (2013).

Head-thumping was observed in two dyadic tests in *T. macrocephalus*. These signals were exhibited by two large males (1150 g and 1164 g) when tested against another large male. No seismic communication was observed in dyadic tests in *E. cansus*. In the field we recorded seismic signals of *T. macrocephalus* in five males and eight females, out of five males and 11 females recorded (Tab. 1, Fig. 1a). Males produced more pulses per bout than females (U=1276.5, p<0.01), but there was no difference between the sexes in inter-pulse distance (U=1587, p=0.23). Most recordings were obtained between 11:00–13:00, with a second smaller peak around 17:00 (Fig. 2b). We recorded two antiphonal exchanges, between two males and two females respectively. We recorded seismic signals of *E. cansus* in the field in two males and six females out of 11 males and 17 females monitored (Tab. 1, Fig. 1b). Sex differences were not evaluated due to the low number of recorded males. Zokors produced seismic signals mainly during the night (22:00–23:00) and during early morning (04:00–07:00; Fig. 2a). We recorded two antiphonal exchanges. The first one was between two females and the second between a female and a male. The comparison of physical properties of seismic communication between four species of spalacids (*S. galili*, *T. splendens*, *T. macrocephalus* and *E. cansus*) by DFA indicated that this signal is species-specific (Wilk´s lambda=0.34, $F_{(6,88)}$=10.53, p<0.001). The best resolution was obtained in *S. galili* (Tab. 2). Body mass was positively correlated with inter-pulse distance in seven spalacids only if *T. macrocephalus* was omitted (r=0.89, p=0.02; if included, the values were: r=0.28, p=0.54). The influence of weight on the number of pulses per bout was not significant (R^2=0.02, p=0.96), even after omitting *T. macrocephalus* (r=0.53, p=0.28).

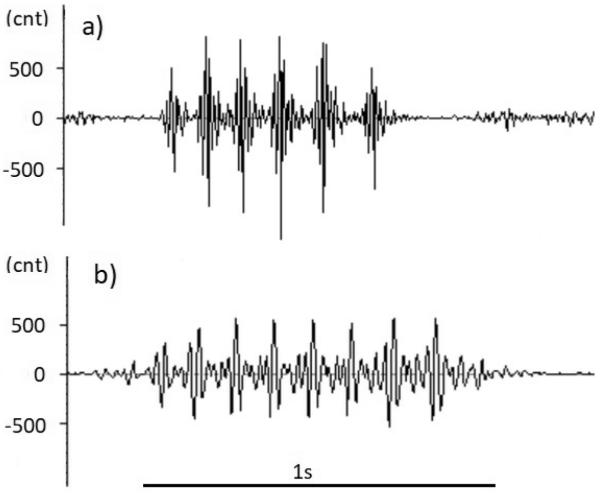

Figure 1 – Oscilogram of one bout of seismic signalling of a) *T. macrocephalus* containing six pulses, b) *E. cansus* containing nine pulses.

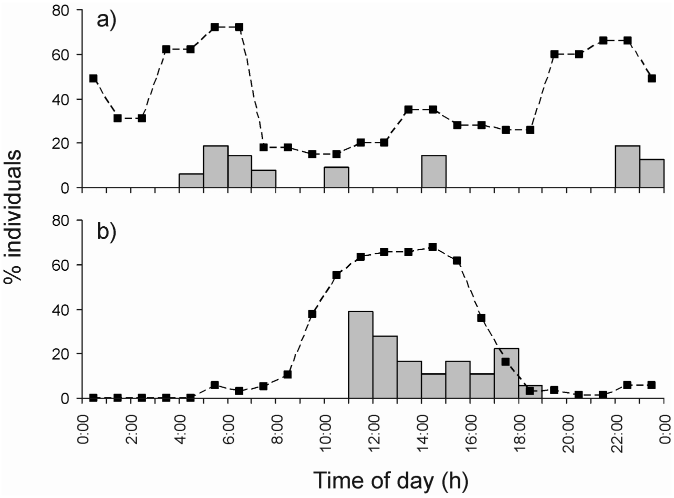

Figure 2 – Proportion of individuals producing seismic signals out of all individuals recorded during 1 h intervals of the 24 h day (grey bars) in a) *E. cansus* (10–20 individuals) and b) *T. macrocephalus* (8–13 individuals). Black squares represent proportions of active individuals at a particular time [adapted from Ji et al. (2018) and Vlasatá et al. (2017)].

Table 2 – The success rate of classification of the signals according to DFA in spalacids, Wilk's lambda is 0.34.

	Percent correct
Spalax galili	86.4
Tachyoryctes daemon	50.0
Eospalax cansus	75.0
Tachyoryctes macrocephalus	61.5
Total	**73.5**

We provide information on the physical characteristics of substrate-born vibrations in two fossorial rodents representing different spalacid genera. We studied individuals in their natural burrow systems, which is a novel approach compared to previous studies. In both species, the period of the most frequent thumping corresponded with their highest activity: in *T. macrocephalus*, for instance, 90% of outside nest activity occurred between 09:00–18:00 (Vlasatá et al., 2017), and two peaks of head-thumping in *E. cansus* corresponded with two peaks of summer activity (15:00–22:00 and 00:00–07:00; Zhou and Dou, 1990; Zhang, 2007; Ji et al., 2018). In *S. ehrenbergi* the seismic signals emitted in the series were used as territorial advertisement (Heth et al., 1987; Rado et al., 1987). Four antiphonal exchanges recorded in our study, of which three were between individuals of the same sex, may suggest the same purpose. However, sexual differences in *T. macrocephalus* signalling suggested that these may be used in a mating context as in the case of the Cape mole-rat (*Georychus capensis*; Narins et al., 1992). The seismic signals in spalacids are species-specific despite their origin in different geographical regions. The allopatric species of kangaroo rats also differ in the physical parameters of their foot-drumming, which could be explained by variation in their habitats, size or social organization (Randall, 1997). The only two species included in this study whose habitats overlap are the root-rats (Norris, 2017). However, we studied animals from geographically distant populations. The neighbouring populations would be more suitable for research of species specificity. Their dialects could be more different, as suggested by the seismic signals in four neighbouring chromosomal species within the *S. ehrenbergi* superspecies (Heth et al., 1991). The relationship between body weight and seismic signal parameters in rodents has been studied only in kangaroo rats. The largest kangaroo rat has a complex signal (several sequences of foot-rolls with up to 69 foot-drums each) with the smallest inter-pulse distance (Randall, 1997). Compared to kangaroo rats, spalacids have simpler signals (2.19–9.53 thumps per bout) and their inter-pulse distance increases with body weight after excluding the largest species *T. macrocephalus*. The opposite trend between body weight and interpulse distance may be caused by different way of production of seismic signals between kangaroo rats (foot-thumping) and spalacids (head-thumping). Among mammals, head-thumping seems to be unique to spalacids, and it has only been described in three spalacid subfamilies: Spalacinae, Myospalacinae and Rhizomyinae (Heth et al., 1987; Rado et al., 1987; Li et al., 2001; Hrouzková et al., 2013; this study). In epigeic mammals, the origin of seismic signals is often explained as a ritualization of a conflict between fight and flight, so the seismic signals are usually produced by foot-thumping (Hill, 2008). Subterranean rodents need to get rid of excavated soil, which they deposit aboveground in mounds or underground in unused burrows. Their seismic communication may have evolved as a ritualization of the tampering of the soil during soil removal. Interestingly, bathyergids use their hind feet to push and tamper the soil, and so they also use their hind feet for thumping (Jarvis and Bennett, 1991; Narins et al., 1992), whereas spalacids use their head for both activities (Heth et al., 1987; Rado et al., 1987; Li et al., 2001; Hrouzková et al., 2013).

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