Quick guide

Singing mice

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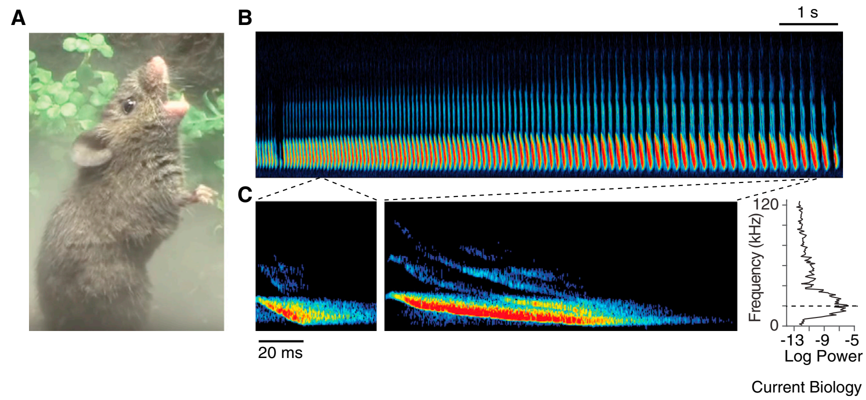

Figure 1. Advertisement song of *S. teguina*.
(A) An adult *S. teguina* singing in an operatic posture. (Image by Bret Pasch, U.T. Austin.) (B) Spectrogram of the full *S. teguina* advertisement song. Dashed lines indicate the two notes depicted in (C). (C) Left: spectrogram of two individual notes at the beginning and end of the song, respectively. Right: power spectrum of the song in (B). Dashed lines denote the end of human audible frequency range.

What are singing mice? Singing mice (genus *Scotinomys*) are small (~12–15g), diurnal, insectivorous, highly vocal rodents belonging to the family Cricetidae. They live in the montane cloud forests and pastures of Central America from southern Mexico to western Panama. Both males and females sing, though males sing much more often. *Scotinomys* vocalizations are frequency-modulated trills consisting of a series of frequency modulated notes that get longer as the song progresses (Figure 1). The singing often involves a male raising his front legs and angling his snout upward in operatic posture (Figure 1A). Initial notes are ~20 milliseconds long, and each is accompanied by coordinated jaw movement and a short exhalation. The resulting songs are high pitched but audible to humans and are sometimes mistaken for an insect or a small bird in the field.

There are two species of *Scotinomys*. Alston's singing mouse (*S. teguina*) is by far more common and makes songs ~6–10 seconds long. A second species, the Chiriqui singing mouse (*S. xerampelinus*), is found only on the highest mountains of Costa Rica and Panama. The sister genus (*Baiomys*) is known as the pygmy mouse, which makes a frequency-modulated song that is shorter, slower and entirely ultrasonic. The elaboration of vocalization seems to have originated in the common ancestor of the two *Scotinomys* species. Because Alston's singing mouse is more abundant in the wild and sings more readily in the lab, most behavior work has been done on this species.

What factors affect* S. teguina *vocalizations? Like other rodents, *S. teguina* pups vocalize extensively. The pup vocalizations consist of highly variable notes similar to ultrasonic vocalizations in *Mus musculus*. Interestingly, after two weeks of silence late in development, adult *S. teguina* songs emerge fully formed. Individuals differ in a variety of acoustic features, such as frequency modulation of notes and the way notes unfold over the course of a song (for example, Figure 1B). Some of these features may encode signals that convey the sender's identity and body condition to listeners. Consistent with this hypothesis, sex hormone levels and nutrient status affect the acoustic structure of songs as well as vocal effort — parameters that also influence female preferences. In general, the songs serve as advertisement signals important in both male–male competition and mate attraction.

Vocal interactions also mediate complex social dynamics between the two species of singing mice. In certain high mountains in Costa Rica and Panama, the two species come into contact with one another. The larger and more aggressive *S. xerampelinus* is dominant to *S. teguina*, and ecological differences in the presence of this congener shape behavioral and neural responses to heterospecific song.

How does social context influence singing behavior? Exposure to conspecifics can elicit robust singing in males. For instance, pairs of males often engage in rapid vocal exchanges known as 'counter-singing'. During these social interactions, males avoid overlapping songs with a vocal rival by quickly stopping when interrupted and resuming immediately after the other mouse has stopped singing (Figure 2). This overlap avoidance and its subsecond timing resemble the 'turn-taking' dynamics of human conversations. An important unresolved question is whether precise counter-singing is shaped by individual experience.

What neural mechanisms govern song production and counter-singing? Recent evidence strongly implicates the motor cortex in mediating aspects of counter-singing. The relevant motor cortical area was mapped by electrically stimulating the anterior cortex while simultaneously monitoring EMG signals in the vocal musculature. Electrical stimulation of the motor cortex disrupts ongoing singing behavior, suggesting that this pathway is involved in song production. Further evidence for this hypothesis comes from mild focal cooling of this portion of motor cortex, which slows down the progression of the motor sequence, resulting in considerably longer songs.

To enable counter-singing in *S. teguina*, the brain must be able to both command the relevant vocal muscles to articulate the song and rapidly modulate singing to coordinate with a vocal partner. Upon reversible

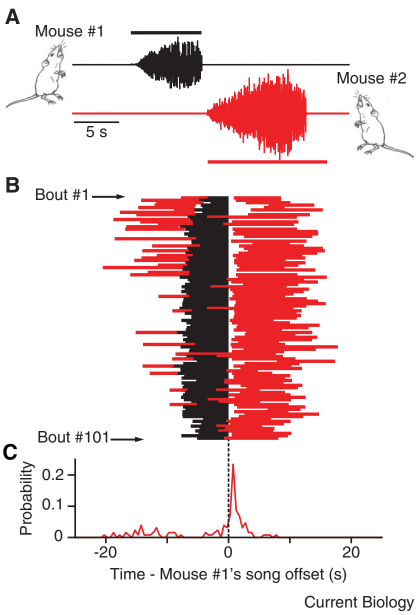

Figure 2. Temporally precise counter-singing in pairs of *S. teguina*.
(A) An example *S. teguina* counter-singing interaction. Sound waveforms are presented for each vocal partner. (B) All vocal interactions in a day (n = 101) wherein Mouse #2 (in red) often responds to the vocalizations of Mouse #1 (in black). (C) Probability of Mouse #2's vocal onsets during counter-singing with Mouse #1. Figure modified from Okobi *et al.* (2019).

pharmacological inactivation of the orofacial aspect of motor cortex, we found that, while the ability to sing remains intact, vocal coordination is severely compromised. These results suggest a hierarchical arrangement, in which song production is mediated by subcortical structures, while the processes capable of coordinating rapid vocal exchanges are controlled cortically. Taken together, multiple lines of evidence point towards a crucial role of motor cortex in *S. teguina* vocal exchanges, enabling us to understand its role in a natural, ethologically relevant social behavior.

What makes singing mice interesting for neuroscience? Understanding the neural mechanisms that allow the brain to perceive sensory input and generate appropriate motor responses is a central theme in neuroscience and is traditionally studied in the lab by training animals to associate simple sensory cues with motor outputs. Although counter-singing behavior in *S. teguina* is a complex sensorimotor behavior, it does not require any training, enabling the study of neural dynamics underlying natural social interactions.

Are singing mice amenable to laboratory study? Yes. They breed throughout the year, and a colony can be maintained in the laboratory relatively easily. Importantly, they exhibit robust vocal behaviors even in a laboratory setting, and many of the natural interactions can be artificially tested using speaker playback assays. Because they are Muroid rodents, reagents developed for lab mice can readily be adopted to the singing mice, including neural circuit-mapping and optogenetic control of specific neuronal subtypes. Studying vocal communication in *S. teguina* and related species provides a great opportunity to understand how the interplay between ecology, evolution and neuroscience shapes social cognition.

Where can I find out more?

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Primer

Marine fungi

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Fungi play a dominant role in terrestrial environments where they thrive in symbiotic associations with plants and animals and are integral to nutrient cycling in diverse ecosystems. Everywhere that moisture and a carbon source coexist in the terrestrial biosphere, fungi are expected to occur. We know that fungi can be devastating to agricultural crops, both in the field and during their storage, and cause mortality in immunocompromised patients in numbers that rival the deaths from malaria. Yet fungi can also be harnessed as sources of food, chemicals and biofuels when humans exploit fungal metabolism. Despite their central role in the health and disease of the terrestrial biosphere, much less is known about the function and potential of marine fungi. Are fungi ubiquitous in marine environments as they are on land? Do they play the same or similar roles in these ecosystems? Here we describe the state of knowledge about the abundance and functions of fungi in the marine environment with a goal to stimulate new inquiry in this very open area.

Fungi in the ocean

Although you will not find them on restaurant menus or on the album covers of psychedelic rock bands, marine fungi do exist. In fact, they exist in every marine habitat where researchers have bothered to look: from hydrothermal vents, subsurface deep-sea sediments, and arctic ice, to surface waters, salt marshes and sandy beaches at low tide (Figure 1). Marine fungi are especially adept at living on or inside other living things like algae, corals, sponges and even other fungi. Even primary producers like dinoflagellates and diatoms are commonly infected by marine fungi, a dynamic that might play an important role in global carbon cycles. Although few researchers have tried to quantify their actual biomass, it seems that this can even exceed that of bacteria, particularly in habitats rich in organic carbon.