Supporting Information

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SI Text

Supporting Text 1

Tagging the Bat's Own Calls – A Solution to the "Cocktail Party Nightmare" of Multi-Bat Calls. As another solution to the 'cocktail party nightmare' problem, the bat could *'tag' the timing of its own calls*, and thus be able to process only its own echoes and ignore the calls and echoes from other bats. One interesting possibility for achieving such tagging was demonstrated in studies by Nobuo Suga and colleagues, who studied the mustached bat (*Pteronotus parnellii*), a CF–FM bat that produces a multiharmonic call which contains most of its energy in the second harmonic (1), similar to the call of *Rhinolophus* shown in Fig. 1*A*. They found neurons in the mustached bat's auditory cortex that responded only when the *pulse* contained the first harmonic and the *echo* contained the second (or higher) harmonic ("combination-sensitive neurons") (1, 2). This suggests that the faint first harmonic of the bat's own call, which is audible to the bat (through air or bone conduction), would activate these combination-sensitive neurons, but the calls of other bats would fail to do so – because the strong atmospheric attenuation of ultrasound (3) would prevent the faint first harmonic produced by other bats from reaching the bat's ears at an audible level, since it needs to travel a few meters in the air. This intriguing mechanism for tagging the bat's own calls and echoes has been demonstrated also in another CF–FM species, the horseshoe bat, *Rhinolophus* (4). However, this mechanism would likely *not* apply to the majority of FM bat species, in which most of the energy is concentrated in the *first* harmonic of their call rather than in the second harmonic (e.g., compare the FM and CF–FM calls in Fig. 1*A*): In bats with such call structure, the strong atmospheric attenuation of high frequencies (i.e., of high harmonics) would preclude detection and combination-sensitivity to higher harmonics of the echoes. Since the largest congregations of bats on Earth are formed by FM bats that have a dominant *first* harmonic (5), i.e., the Brazilian free-tailed bat (Fig. 3 *A* and *B*), this suggests that many FM bat species must use other mechanisms.

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Supporting Text 2

Range-Dependent Adjustments in the Calls of a Bat as It Attacks an Insect: Several changes occur in the bat's sonar calls as it attacks an insect. First, as the bat approaches the target, it emits the next call after receiving the echo from the previous call (1), which results in an increased call-rate as the bat closes in on the target; this effectively increases the update rate of the bat's stroboscopic sonar system, which is helpful during high-speed aerobatic chases of insects. Second, the bandwidth of the call increases with the approach to the target (Fig. 1*B*), and an increased bandwidth is known from sonar theory to improve the range-estimation accuracy (2), thus enhancing the precision of the bat's attack. Third, the duration of the bat's call decreases with its approach to the target, and this allows the bat to avoid the difficulties associated with detecting the target's faint echo while still emitting its extremely loud call, whose intensity can reach >130 dB SPL at 10 cm (3). Reduced sensitivity to echoes that arrive close to the time of sonar emission occurs because of middle-ear muscle contraction during the vocalization (4) and neural attenuation in the brainstem (5); the reduction of the call duration during the attack phase allows the bat to separate in time the call from the echo and to avoid overlap between the two, thus helping the bat to continue tracking the insect even at very short distances.

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Supporting Text 3

Changes in the Spectro-Temporal "Shape" of Echolocation Calls May Minimize the Systematic Errors Introduced into the Ranging Estimate by the Bat's Own Motion. These flight-related errors are introduced because the bat emits its calls in one position and hears the echo at a slightly different position, and because of the Doppler shift of the echo frequencies – both of which distort the computation of target range (1, 2). Importantly, there is a certain physical distance from the bat at which these two errors cancel out, and targets located at that distance are localized accurately: This distance was termed the 'distance of focus', and it turns out to depend on the detailed shape of the frequency-modulated call, such as its sweep-rate and curvature (1, 2). A recent study has shown that bats flying along a hedge adaptively changed the spectro-temporal shape of their calls so as to maintain the instantaneous distance to the hedge within the distance of focus, thus minimizing the ranging errors, and presumably reducing the risk of collision (2).

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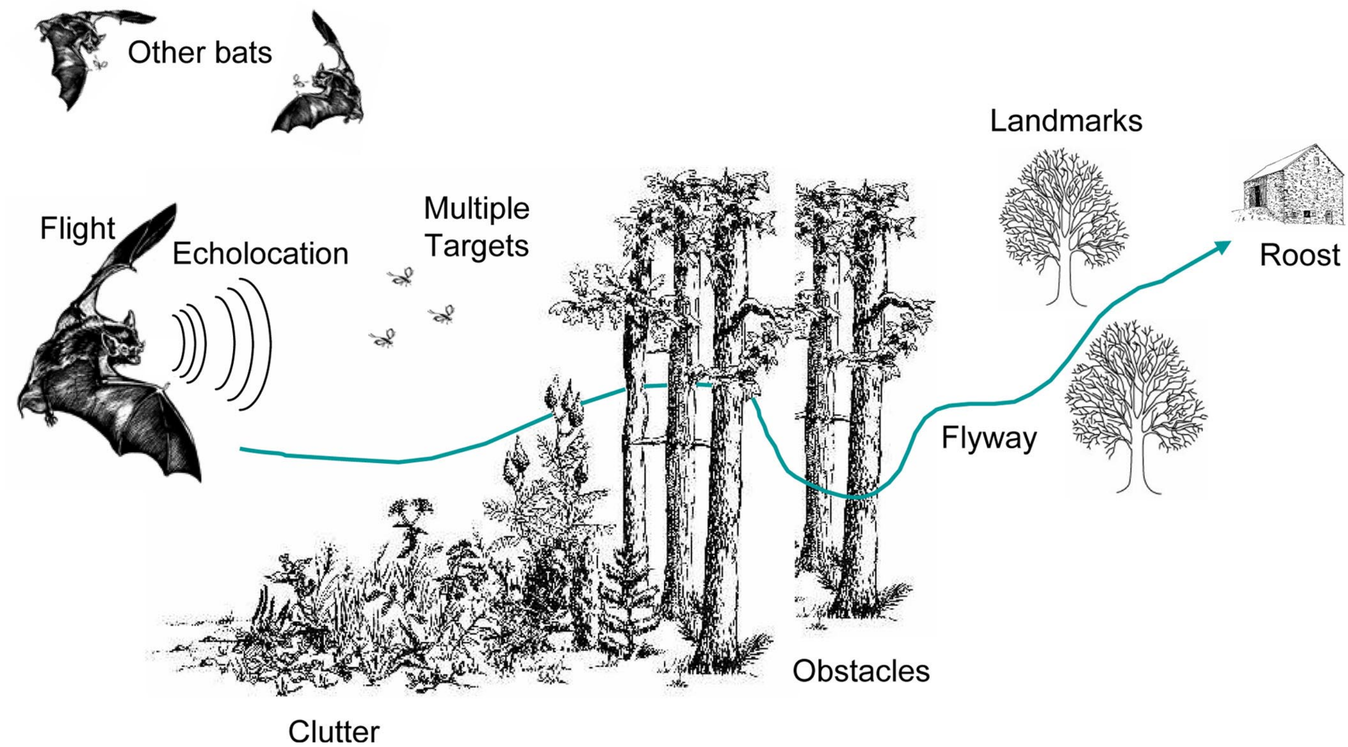

Fig. S1. What is it like to be a bat? When foraging in real-life situations, the echolocating bat faces multiple complex tasks. To illustrate this, consider a nightly feeding flight (see figure): The bat leaves its roost and flies toward the hunting grounds, often following well-remembered routes, called 'flyways' (1–5). Obstacles may be present on the way, but the bat dodges branches and telephone wires with ease. Then the bat arrives at its feeding territory, where it hunts for insects while having to avoid collisions with obstacles such as trees or light posts, and it has to ignore the confusing echoes that return from various 'clutter' objects such as bushes or the ground. Moreover, the bat often does all this in the presence of many other bats (6), whose vocalizations may introduce substantial acoustic interference, or 'jamming' of the bat's echolocation. The bat may also engage in drinking passes at a local water hole, which are done in-flight, while avoiding potentially-fatal aerial collisions with other drinking bats or with the water surface (7) – and all of this must be done while keeping an open ear for the approach of predators, such as bat hawks. The bat then flies back to its roost, relying on its spatial memory: many bats return night after night to the same roosting spot, such as the same crevice inside a complex cave or the same roosting tree in the forest (8–10), or – if it is a female – it may need to find its pup in the cave, sometimes among several millions of other pups that are screaming for their mothers (11). The execution of these behaviors requires three key elements, on which the paper focuses: (*i*) Auditory scene analysis; (*ii*) Sensorimotor transformations; (*iii*) Spatial memory.

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