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OUTSIDE JEB

Listen up – jumping spiders can hear airborne sounds

Jumping spiders (Salticidae) are renowned dancers, but until recently, the music of their courtship was thought to fall on deaf ears. No one had heard of spiders being able to perceive sounds until a recent serendipitous finding published in *Current Biology* by Ronald Hoy and colleagues from Cornell University, USA. Having previously shown that the spiders rely heavily on vision as they strut their stuff, Hoy's colleagues, Paul Shamble and Gil Menda, were intrigued when they noticed that the spiders also reacted to sounds made by a creaky lab chair: the noises triggered nerve signals in the spider's brain. This led to subsequent experiments where clapping elicited more brain activity, and eventually the researchers designed a more detailed series of experiments designed to test the spiders' hearing more thoroughly.

First, Menda carefully inserted an electrode into a jumping spider's (*Phidippus audax*) main brain area, which is thought to be important for interpreting the senses. Once the researchers inserted the electrode, they played a series of tones ranging in frequency (50–400 Hz) and amplitude (volume) to the spiders. Importantly, the scientists ensured that the sounds were being transmitted through the air, and not the surface that the spiders were standing on, by placing the spiders on a vibration-free air table. Brain recordings made by Shamble and Menda revealed that single neurons were sensitive for a narrow range of frequencies, similar to tuning curves in other species. Moreover, they realised that neurons fired more in response to frequencies important to the spider at lower amplitudes, suggesting that the brain can hear salient sounds from longer distances.

While the neural responses suggest that sounds are perceived, it was unclear whether spiders would respond to the tones. To investigate this, the team played notes either at 80 or 2000 Hz while filming the spider's behavioural responses. Interestingly, the spiders froze almost instantaneously when they presented low-frequency tones, but didn't react to high-frequency sounds. Shamble and Menda explain that common spider predators, such as wasps, produce sounds around 100 Hz, which are well within the hearing range of these jumping spiders and so the deeper tones could possibly be interpreted as a threat.

However, how a spider actually 'hears' sound was still a mystery. Spider legs are covered with air-flow-detecting hairs, which may translate airborne sounds into neural activity and subsequent behavioural responses. To test whether these sensory hairs encoded airborne sounds, Shamble and Menda stimulated individual hairs on the spider's foreleg using a microshaker. Vibrating the leg hairs over the same frequency range that the spiders could hear triggered nerve signals in the spiders' brain, which were the same as the signals that they had recorded when playing sound to the arachnids. This suggests that the sensory hairs are likely involved in perceiving sound, although the authors caution that proving a direct link between sound perception, the leg hairs and nerve signals in the brain is a nontrivial task that is yet to be completed.

In what started as a fortuitous creaky chair incident, Shamble and colleagues have found that jumping spiders can detect and respond to long-range airborne sound – both at the neural and behavioural levels – which may be important for predator detection and finding a mate. So next time you reach for a can of Raid, just remember, spiders may be able to hear you plotting their demise.

10.1242/jeb.147223

Shamble, P. S., Menda, G., Golden, J. R., Nitzany, E. I., Walden, K., Beatus, T., Elias, D. O., Cohen, I., Miles, R. N. and Hoy, R. R. (2016). Airborne acoustic perception by a jumping spider. *Curr. Biol.* **26**, 1-8.

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Climate change delivers a punch to the gut

Climate change, one of the most important environmental issues facing the contemporary world, has significant impacts on biodiversity. Whether you are a denier or a supporter of the role of humans in climate change, there is no doubt that the Earth's temperature is rising. Although rising global temperatures are known to directly affect biodiversity, there is now emerging evidence that they also have indirect effects, by disrupting the symbiotic relationships that some species have with their gut bacteria.

Insects are particularly dependent on their bacterial gut symbionts, because the bacteria digest food that the host cannot on its own. This offers the insect an advantage, allowing it to absorb more nutrients. For the southern green stink bug (*Nezara viridula*) – a notorious pest infesting crops worldwide – the relationship with its gut symbiont is vital. The females pass the symbionts on to their larvae by smearing a gut excretion – containing symbiotic bacteria – over the

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eggs when she lays them, which the larvae then consume. This external transfer of the bacteria to the eggs is believed to be the source of their symbiotic lodgers. Sterilization of the eggs, which eliminates the bacteria, leads to significant delays in development, reductions in growth and even death. As the gut bacteria are at risk when exposed to environmental conditions during transfer to the stink bug larvae and because of the essential symbiotic relationship between the bug and its bacterial lodgers, the stink bug is an ideal example of an animal that can teach us about the indirect effects of increasing global temperatures on biodiversity.

Yoshitomo Kikuchi, from the National Institute of Advanced Industrial Science and Technology (AIST), Japan, and his colleagues designed a set of experiments to investigate the role of rising temperatures on the symbiosis between the stink bug and its gut bacteria. In the first experiment, the authors collected eggs from the stink bugs in midsummer and grew them under simulated warming conditions (2.5°C warmer than natural). They found that the higher incubation temperature led to smaller body size in adults, altered their coloration and reduced survival. In addition, the population of symbiotic bacteria in the bug's gut was significantly reduced under these conditions. In the second experiment, the team exposed stink bug eggs to temperatures ranging from 25 to 35°C and found similar defects in the bugs that developed at 30°C, while few insects survived the higher temperatures. The authors also recorded significant reductions in the levels of the gut bacterial symbiont in the individuals incubated at temperatures above 30°C.

To determine whether the temperature effects noted in the stink bug were correlated to effects on the symbiotic relationship with their gut flora, Kikuchi and colleagues eliminated the gut bacteria by administering a low-dose antibiotic to the females and then monitored the development of their offspring into adulthood. Impressively, they discovered that the offspring that had not been provided with the symbiotic bacterial boost by their mothers were smaller, had abnormal coloring and lower survival rates, just like the bug youngsters that had been incubated at higher temperatures. This suggests that higher environmental temperatures may affect the symbiotic gut flora directly, impairing the development, growth and survival of their stink bug hosts.

This study of Kikuchi and colleagues is one of the few to show that increases in temperature affect the vital symbiotic relationship between insects and their bacterial symbionts. While the direct effects of global temperature increases on biodiversity have been well documented, it appears that they extend even to symbiotic lodgers. Climate change delivers yet another punch in the gut of biodiversity.

10.1242/jeb.147256

Kikuchi, Y., Tada, A., Musolin, D. L., Hari, N., Hosokawa, T., Fujisaki, K. and Fukatsu, T. (2016). Collapse of insect–microbe symbiosis under simulated climate change. *mBio* **7**, e01578-16.

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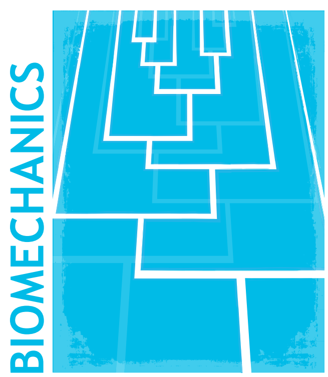
Flexible fins may help fish climb on land



Fishes exhibit a wide variety of shapes and sizes that allow them to perform an impressive range of behaviours, from swimming to gliding and even rock climbing. While a rock-climbing fish may sound odd, numerous fishes do so using climbing gear built into their bodies. Climbing can be beneficial – to avoid predators – but can be risky too, because one slip could be fatal. Consequently, climbers must attach themselves securely to the climbing surface. Some fishes climb with little more than their fins and a dab of mucus, but what makes some species stickier than others? Adhityo Wicaksono, from Abo Akademi University, Finland, and colleagues from several international institutions compared climbing and non-climbing species of mudskipper fishes to evaluate which features might help them ascend trees and rocks in their natural habitats.

Mudskippers are highly terrestrial fish and have numerous adaptations for moving on land, including pelvic fins, which can differ significantly between climbing and non-climbing species. For example, *Boleophthalmus boddarti* does not climb, yet it has pelvic fins that are fused into a suction disk, whereas *Periophthalmus variabilis* can climb and has unfused pelvic fins. Pelvic fins can be particularly important climbing structures because mudskippers and other gobies use them to attach to surfaces in between movements. To test the hypothesis that unfused pelvic fins may aid climbing in mudskippers, Wicaksono and colleagues integrated experimental techniques with computer simulations to compare how pelvic fin structure or the mucous secreted by the fins related to the fishes' climbing abilities. The team measured how well the pelvic fins resisted being dislodged from a surface in different directions, evaluated whether the chemical composition of the mucous surrounding the pelvic fins improved adhesion, and then estimated how much weight the fins could bear.

The authors found that the climbing mudskipper had more flexible pelvic fins than the non-climbing species, which could increase contact and adhesion during an ascent. The chemical composition of the mucous secreted by the pelvic fins was relatively similar across the mudskippers and particularly good at sticking to surfaces that the fish climb in nature, such as rocks. Wicaksono and his team also found that the unfused fins of the climbing species better resisted disturbances parallel to the line of movement, which might help reduce slippage while climbing. In contrast, they found that the non-climbing species was better at resisting disturbances perpendicular to its line of movement, potentially improving its ability to hold on tight to rock surfaces in the surf. Although the climbing species was smaller, it had larger pelvic fins relative to its body size. Smaller bodies can make climbing easier by reducing the weight that the pelvic fins have to support, and may provide additional benefits on land, such as making it easier to maintain their body temperature and prevent dehydration from excessive water loss through the skin.

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Together, these results broaden our perspective of how interactions between organisms and their environment can relate to the form and function of physical characteristics. The study also shows that integrating various approaches provides a finer lens for studying the mechanistic causes of biodiversity. And when it comes to climbing with mudskipper fins, it may pay to be more flexible.

10.1242/jeb.147215

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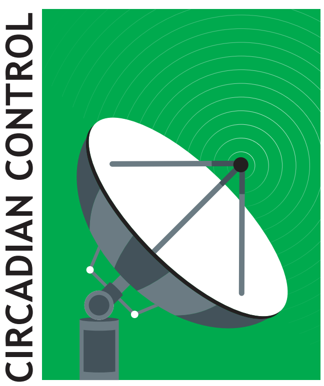
Singing fish take their cues from melatonin



The Pacific coast of North America is home to a truly peculiar toadfish, the plainfin midshipman (*Porichthys notatus*). Male midshipman fish nest under rocks in the intertidal zone and 'sing' to attract female mates to their nests. Midshipman fish only sing their courtship song at night, and the song is a low, continuous hum (~100 Hz) that males make by twitching specialized sonic muscles on their swim bladders. These muscles can twitch at an amazing rate, upwards of 100 contractions per second, which is one of the fastest twitching muscles in any vertebrate.

But how do midshipman fish know to sing their songs at night? Like songbirds that call during the day, do midshipman fish use hormonal cues to govern their vocalizations? These questions captured the attention of Ni Feng and Andrew Bass, from Cornell University, USA. The pair set out to examine whether melatonin, a time-keeping hormone in vertebrates, might control midshipman song.

Melatonin production follows a circadian rhythm that translates the light–dark signal of the rising and setting sun into an internal hormonal signal. The role of melatonin is often inhibitory in day-active, diurnal animals such as songbirds: when melatonin concentrations increase after sunset, animal activity and song production are suppressed. Melatonin provides animals with cues about when to be active and when to rest during their daily cycle.

Feng and Bass tested whether the nocturnal courtship call of the midshipman was under circadian control and stimulated by melatonin. The pair of investigators experimentally changed external light cycles in the male midshipman's tanks using programmable lighting and altered their internal melatonin levels using implants that would mimic melatonin's action. Feng and Bass then recorded how male courtship song changed under these varying conditions.

Under normal light–dark conditions, the researchers found that midshipman song had a circadian rhythm and the fish would only sing at night. However, when the researchers placed the fish under constant light, their daily rhythm of singing was suppressed. Constant light inhibited their singing cycles, likely because melatonin was also suppressed. Next, Feng and Bass implanted midshipman fish with a melatonin mimic to test whether they could 'rescue' male song under constant light, by adding a melatonin cue, and this time the fish began singing again. The hormone can trigger singing, even in daylight.

But how does melatonin cue the midshipman's reproductive ballads? To answer this final question, Feng and Bass mapped melatonin receptors in the brain of midshipman fish. They found that melatonin receptors were indeed concentrated in areas of the brain that govern reproductive behaviours and song production. This map nicely linked melatonin to the daily regulation of such behaviours.

Feng and Bass have interestingly shown that melatonin acts in the opposite direction to most diurnal animals: it actually stimulates song production at night in these nocturnal fish, rather than suppressing it. Their elegant series of experiments showed that regular cues from melatonin ensure that midshipman fish keep their nightly courtship serenades on time.

10.1242/jeb.147249

Feng, N. Y. and Bass, A. H. (2016). 'Singing' fish rely on circadian rhythm and melatonin for the timing of nocturnal courtship vocalization. *Current Biology* **26**, 1-9.

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