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THE SECRET SUPERPOWER OF MOTHS: SOUND-ABSORBING STEALTH CAMOUFLAGE

*Marc W. Holderied**

School of Biological Sciences, University of Bristol, Bristol, United Kingdom

YOUNG REVIEWER:

BRYSON
AGE: 8

Today's military aircraft typically use highly engineered "stealth" coatings that make them almost invisible to radar. Nature might seem an unlikely place to find such advanced technology, but one should never underestimate the ingenuity of evolution—moths developed their own form of stealth cloaking over 60 million years ago! That is before humans even walked the Earth! We discovered that the tiny scales on moth wings, which form fine dust when touched, provide stealth camouflage against the sonar used by their most dangerous foes—bats. By absorbing bats' high-pitched calls, moths become nearly invisible to bats. Such stealth camouflage is a true superpower, as the coating on moth wings is light enough to allow flight, while still absorbing all the sounds bats make. The moths' trick is that scales of various shapes work together to create a powerful super-absorber that is now inspiring humans to develop new sound-absorbing materials of our own.

EVERYBODY WANTS TO CATCH A MOTH

The life of a moth is full of dangers. Whether a moth is hiding during the day or flying at dusk, predators will be on the prowl, trying to catch a tasty snack. Spiders, birds, monkeys, bats, and even the grizzly bears of the Rocky Mountains love to feast on juicy moths[1]. To make things worse, moths do not have hard armor or stinging tails to protect themselves. Instead, evolution has equipped moths with a remarkable defense that no other insect has: a dense coat of hairs and scales made from a substance called chitin, which helps moths to evade and escape many kinds of predators (Figure 1)!

[1] Main, D. 2015. *Grizzly Bears Can Eat 40,000 Moths in a Day*. Newsweek. Available online at: *https://www.newsweek.com/grizzly-bears-can-eat-40000-moths-day-400281*.

A moth's entire body, except its eyes and wing joints, is densely covered in these hairs. They form a sort of dense fur on the main parts of a moth's body and they are flattened into overlapping spade-shaped scales on the wings. But how can fur and scales protect a small moth from being eaten by a spider, a monkey, or a bat? Amazingly, a moth caught in a spider's web can escape because the scales that are stuck to the web simply break off at their bases. Parallel ridges on the scales make them slippery, helping moths to slide out of a monkey's grasp or a bird's beak. Also, birds and other predators looking for prey are fooled because the scales create camouflaging or confusing color patterns [1]. But the most amazing thing of all is that the scales actually help moths hide from their most fearsome predator—bats.

HUNTING WITH SOUND

Most bats hunt at night. While other night-time predators, like owls, have incredible eyesight to help them spot their prey in the dark, bats find their way around using sound. We call this **echolocation**. Bats make tiny squeaking sounds that bounce off nearby surfaces, creating echoes that the bats then pick up with their sometimes-enormous ears. Bats have extremely sensitive hearing—they can move around in complete darkness and can tell whether their squeaks have echoed

ECHOLOCATION

Some animals emit sounds and then listen for the returning echoes which help them paint an acoustic image of the world even in complete darkness. A bat's super-power.

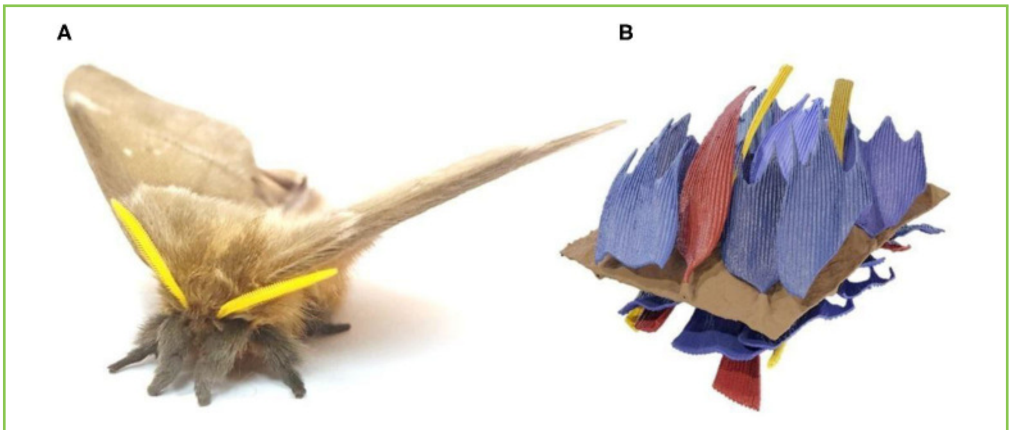

Figure 1

(A) A very furry silk moth (Photograph credit: T. Neil). **(B)** A microscopic false-color image of a small section of a moth wing, showing spade-shaped (blue), lanceolate (red), and hair-like (yellow) scales on both sides of the brown wing membrane (3D model: S. Reichel).

off a tree, a building, or a flapping insect such as a tasty moth. We call this bio-sonar and it is a bat's superpower!

How, then, can a moth defend itself against such an ingenious biosonar? Some moths have ears and can hear the calls of an approaching bat and fly away. But most moths are deaf and do not even notice when they are under attack by a bat. Instead, they rely on the amazing ability of their hairs and scales to absorb, or soak up, the bats' squeaks rather than reflecting them back to the bats' ears. We might say they have an **acoustic** "stealth cloak" that helps them disappear from a bat's biosonar. Keep reading to discover the surprising secret behind a moth's stealth cloak!

ACOUSTIC

Anything to do with sound.

THE STEALTHY MOTH IS FURRY

Have you ever been inside a large, echoey building such as a church or large hall? You might have noticed that these spaces do not have many carpets, curtains, or other soft furniture. In our homes, schools, and offices, these soft materials absorb sounds, which helps make these spaces quieter places to live and learn. When sounds hit a hard surface, they bounce off, creating an echo. But when sounds hit softer materials, such as carpets or cushions, they bounce around in the tiny spaces *inside* the material and are trapped and absorbed. We call these tiny spaces pores, so these soft materials are called **porous absorbers**.

POROUS ABSORBER

A material that has many interconnected holes and cavities (like a sponge) in which sound enters and then is absorbed.

In a similar way, the hairs and scales on a moth's body also absorb sounds, including the squeaks made by bats. Sound is created by vibrations moving through the air. The faster the vibrations, the higher the **frequency** of the sound. So, a high-pitched bat squeak will have a high frequency, whereas a low-pitched cannon boom will have a low frequency. Porous absorbers are much better at trapping high-frequency sounds. Even a thin layer can trap the highest-frequency sounds. But to absorb lower-frequency sounds, the porous absorbers must be much thicker. The fur on a moth's body is around 2 mm thick, which is exactly the right thickness to absorb the lowest sounds used by bats for echolocation. In fact, we have discovered that moths with fur are *half as likely* to be caught by bats than moths with no fur [2]!

FREQUENCY

Describes how fast a sound wave oscillates. Fast-oscillating, high frequency sounds have a high pitch and slowly oscillating low-frequency sounds have a low pitch.

SCALY WINGS ARE POWERFUL SOUND ABSORBERS

So, the fluff on the moths' bodies is great at helping them hide from bats. But a moth's wings aren't hairy, so why can't a bat just detect echoes bouncing off the smooth wings? Obviously, a moth's wings would not work very well if they were covered in long hairs, so moths have evolved an even more fascinating way to make sure their wings are hidden too. Moth wings use what is called **resonant sound absorption**.

To understand resonance, imagine you are pushing your friend on a swing in the playground. You must push the swing at exactly the right time to make it go higher and higher. If you push at the wrong time, you can even completely stop it from swinging. We call the timing of this ideal push the **resonance frequency** of the swing. In the same way, objects can have different resonant frequencies for sound.

Sounds travel through the air as waves, rather like the waves on the ocean. The distance between the top of one wave and the top of the next is called the **wavelength**. Porous absorbers, such as the hairs on a moth's body, need to be 1/10 as long or thick as the sound's wavelength to absorb the sound. But resonant sound absorbers only need to be 1/100 as thick as the sound's wavelength, which makes them perfect for moth wings. The resonant absorbers on a moth's wings take the form of spade-shaped flattened scales (Figure 1B). When sound of the resonance frequency hits such a scale, the scale will start to vibrate. The **energy** contained in the sound is turned into kinetic energy, or movement of the scale, which results in the sound being absorbed.

Resonant absorbers, such as the vibrating scales on a moth's wings, only absorb sound at a single frequency. Because bats use many sound frequencies during echolocation, a single resonant absorber would only remove one part of the echo, and the bat could still find the moth by its remaining echo [3]. To combat this, each scale on a moth's wing has a slightly different size and shape (Figure 1B) and, as a result, each scale has a slightly different resonance frequency. In fact, when we looked closely at moth wings, we discovered that they have variously shaped scales that cover all the resonance frequencies of bat's squeaks! Each scale absorbs its own frequency and, together, all the scales absorb all the bat's frequencies. We even found that the overlapping scales interact with each other, making them more absorbent as a group than they are by themselves. This super-absorption power makes moths' wings an **acoustic metamaterial**—a structure so good at absorbing sound it has not yet been found anywhere else in nature [3].

INSPIRING SUPERMOTHS

In summary, while moths lack the hard shell of a beetle or the sting of a wasp, they have evolved an incredibly clever way to protect themselves from being found and eaten by predators. Not only do their hairs and scales make moths slippery and difficult to keep hold of, these structures also form one of nature's most complex materials, which acts as a sort of stealth cloak, keeping moths hidden from bats—their most dangerous adversaries (Figure 2).

RESONANT SOUND ABSORPTION

Can be 10× thinner than a Porous absorber (see above) and works by many small resonators that each absorb one frequency (see Resonant frequency), and together they absorb all frequencies.

RESONANCE FREQUENCY

An organ pipe, a swing in the playground or a moth scale are all resonators. They respond when stimulated with the exact right frequency—their resonance frequency.

WAVELENGTH

In all types of waves—e.g., waves on the ocean or sound wave—the distance between the top of one wave and the top of the next is called its wavelength.

ENERGY

The ability to do work.

ACOUSTIC METAMATERIAL

A material made from many subunits (like moth scales) whose interaction creates effects going beyond the sum of the individual elements.

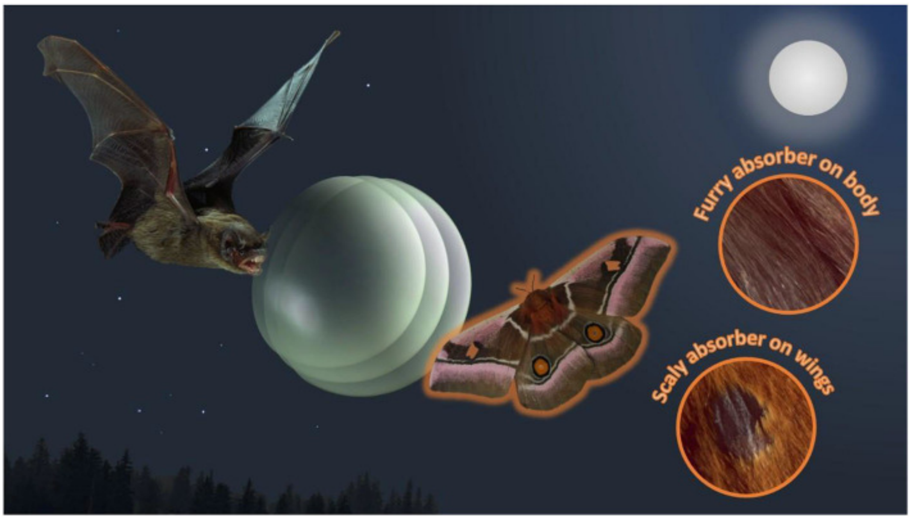

Figure 2

Figure 2

A bat hunting a moth using echolocation. The moth is equipped with a stealth cloak that absorbs the bat's call and protects it against detection by the bat's biosonar. The sound absorber on the body is thick fur and the absorber on the wings is a much thinner layer of flattened scales that form a sound-absorbing metamaterial (Photograph credit: D. Nill and T. Neil).

These tiny superheroes have inspired humans to develop better ways of controlling sound in our own homes, buildings, cars, and airplanes. By understanding exactly how moth wings work, we might be able to build thinner, lighter materials to absorb sound, helping to create quieter, more pleasant environments for us all.

As for staying safe from grizzly bears...unfortunately, no amount of hair or scales can protect moths against these giants. Perhaps one day, a cloud of scales might get up a bear's nose, making him sneeze out his snack and letting our mighty moth live another day. Good luck little moths!

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ORIGINAL SOURCE ARTICLE

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CONFLICT OF INTEREST: The author declares that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

YOUNG REVIEWER

BRYSON, AGE: 8

I am Bryson. I am 8 years old and in the third grade. I like to review the papers because I think that they are fascinating.

AUTHOR

MARC W. HOLDERIED

Professor Marc Holderied is a sensory biologist and bioacoustician with strong links to bio-inspired engineering. He researches acoustic camouflage and biosonar navigation, with a continued passion for acoustic arms races and wildlife acoustics. He consults the automotive industry to develop Ultrasonic Vision technology, and he leads the free-for-all Bioacoustics Special Interest Group at UKAN (acoustics.ac.uk). *bzmwh@bristol.ac.uk