Unmistakably a rodent: Ansell's mole-rat *(Fukomys anselli)* is one of about a dozen species of African mole-rats. Its powerful incisors are constantly growing. The animal uses these when digging its tunnels to loosen the soil, kicking it backwards with its front and hind legs.

PHOTO: CHRISTOF SEELBACH FOR MPG

RODENTS WITH AN INNER COMPASS

TEXT: ANDREAS LORENZ-MEYER

Magnetic fields have no smell or taste, they are invisible, and they do not make any noise. As a result, we humans are not able to sense them on our own. The African mole-rat, on the other hand, has a magnetic sense or magnetoreception that it uses to find its way in the darkness. Pascal Malkemper and his team at the Max Planck Institute for Neurobiology of Behavior – caesar in Bonn are studying how this subterranean rodent senses magnetic fields.

As soon as the light goes on in the room with the mole-rats, the rustling begins. Every so often, an elongated body with light brown fur emerges from the tunnels and chambers in the cages, before disappearing again. There is a sudden thumping sound. “Those are warning signals,” whispers Pascal Malkemper. “See this animal in the tube here! It makes undulating movements with its body, creating vibrations.” The message does not go unanswered: a conspecific appears at the other end of the tube and responds by thumping.

The African mole-rats’ room is full of cages, of which plexiglass tubes always connect two. The temperature is 26 degrees and the humidity is over 60 percent, matching the conditions underground in Zambia. This species is not found anywhere else in the world. The cages are designed to provide for the rodents’ habitat requirements. The animals live in family groups and move around for their entire lives in tunnels, simulated by the tubes. The cages provide a latrine chamber, a sleeping chamber, and a food chamber. There are pieces of potato or carrot to eat, and sometimes apple too. However, there is no need for a water dispenser, because these African mole-rats do not drink. They take up all water through their food.

In the wild, the animals inhabit underground tunnel systems that can be several kilometers long. They live in permanent darkness and yet they find their ways perfectly fine in this maze of narrow passageways. They head for the various chambers with instinctive certainty – and they are intimately acquainted with the location of the food chamber where they stash the roots and tubers.

Eyes, noses, and ears help guide the African mole-rats only to a limited extent in their underground burrow system. To find their way, the animals use a special sense called magnetoreception. It has been known for some time that these creatures can sense the earth’s magnetic field. This ability is not unique within the animal kingdom as fish, turtles, amphibians, and bats have it too. Migratory birds are also guided by the earth’s magnetic field, and their magnetic sense is well studied. It is probably located in the eye.

Birds have what is called an inclination compass. This means that they sense only the inclination angle at which the magnetic field lines meet the earth’s surface. At the equator, this angle equals zero, and the farther a bird flies to the north or south, the larger the angle becomes. As a consequence, birds cannot distinguish between the magnetic south and north poles. They are either flying towards a pole or towards the equator. Little is known so far about magnetoreception in mammals, but the mechanism appears to be fundamentally different from that in birds. African mole-rats have a polarity compass that, like a compass needle, is oriented to the two magnetic poles of the earth. While the birds’ magnetic compass requires light, that of the mole-rats works even in complete darkness.

Pascal Malkemper chose the African mole-rats (of the genus Fukomys) because they are the only known rodents to use the earth’s magnetic field for orientation. It is still uncertain whether their relatives, the naked mole-rats (which are kept in many a laboratory), can likewise sense magnetic fields. Keeping African mole-rats is also a bit easier than naked mole-rats because, thanks to their fur, they are better able to maintain their body temperature and because their colonies of two to 12 individuals are considerably smaller than those of the naked mole-rats, which can consist of as many as 300 animals.

“Magnetoreception seems to occupy an inferior position in the hierarchy of the senses.”

PASCAL MALKEMPER

Optical sagittal section through the African mole-rat brain. In the cerebral cortex, the researchers came across neurons (arrows) that might be involved in processing information from the magnetic sense.

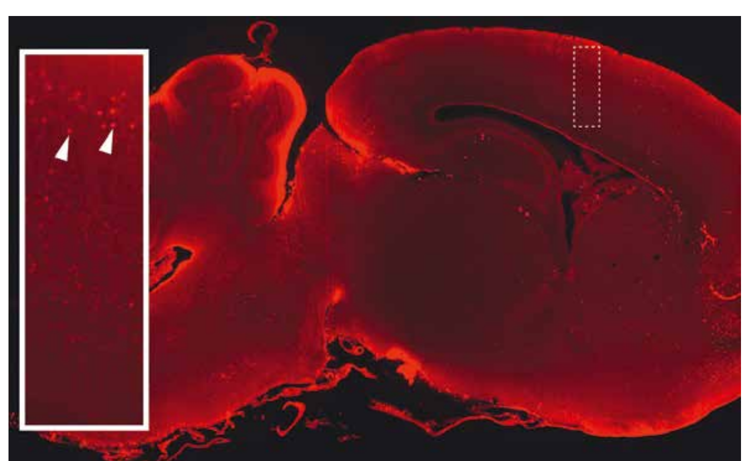

IMAGE: PASCAL MALKEMPER/MPI FOR NEUROBIOLOGY OF BEHAVIOR

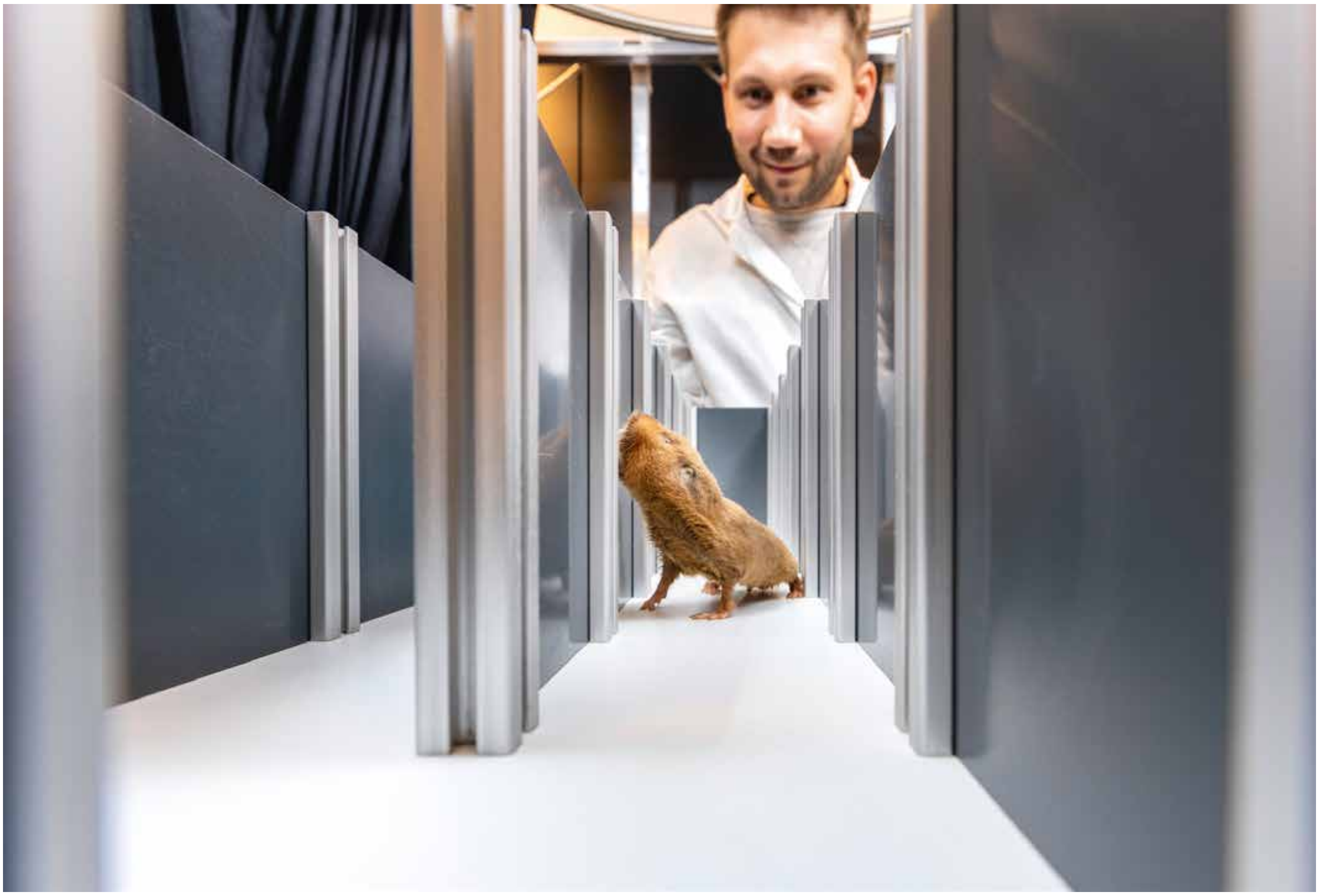

PHOTO: CHRISTOF SEELBACH FOR MPG

Pascal Malkemper is investigating the orientation capabilities of African mole-rats in a maze. The corridor system is located in an artificial magnetic field, which the animals use for orientation.

Pascal Malkemper opens a heavy steel door and enters a small room. On a table inside is a maze, with corridors that the researchers can open and close using flaps. The room is filled with a construction of rods and struts, which surrounds the table. "Many kilometers of copper wire are wound up in this coil system. When current flows through these wires, a magnetic field is generated within the coil that we can control precisely. It allows us to create artificial magnetic fields of all kinds," explains Malkemper.

Virtual reality for mole-rats

During the experiments, the researchers offset the real geomagnetic field of the earth with magnetic coils, at the same time simulating a new geomagnetic field. In addition, black curtains shield the miniature maze, thus preventing the animals from being guided by visual stimuli in the room during an experiment. The maze is also isolated from noises and vibrations; the rodents should not be distracted by anything. Since they could even be disturbed by odors, the chamber is meticulously cleaned after each run. "So it's a low-stimulus environment, except for the artificial magnetic field. This way, we ensure that our measurements can be attributed solely to the animals' magnetic sense," Malkemper explains.

Like most creatures, African mole-rats always use all of their senses. In many cases, if they hear or smell something, they prefer to orient themselves to this rather than to the magnetic signals. "Magnetoreception generally seems to occupy rather an inferior position in the hierarchy of the senses. One reason for this could be that the signal-to-noise ratio is low due to the low intensity of the earth's magnetic field."

Malkemper's team was able to show that the African mole-rats use their magnetic sense for orientation by means of a simple experiment in the maze. Animals that have previously learned to locate a chamber con-

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Well placed: the research group, consisting of Runita Shirdhankar, Alessia Atzori, Pascal Malkemper, Georgina Fenton, Li Zhang, and Sybille Wolf-Kümmeth.

PHOTO: CHRISTOF SEELBACH FOR MPG

SUMMARY

The research group wants to understand where and how magnetic information is processed in the brain of the African mole-rat.

Initial findings indicate that the sensory cells for magnetoreception are located in the eyes.

taining food within the maze take much longer to find their way to the food if the artificial magnetic field around the labyrinth is changed so that their orientation is confused. However, it is not only the direction of the earth's magnetic field that African mole-rats might use as an aid to orientation in the wild. A question that remains unanswered is what role is played by local magnetic anomalies that are caused in nature by iron ores, for example. They might be used by the animals as magnetic landmarks. In the magnetic field chamber at the Max Planck Institute in Bonn, magnetic anomalies such as these can also be created. "We want to test whether anomalies of this sort make it easier for the animals to navigate within the labyrinth, like markings or signs on the walls of a maze would help to guide a person. For this purpose, we can alter the magnetic field in real time, dependent on the position of the animal in the maze – sort of virtual reality for mole-rats," says Malkemper.

Pascal Malkemper and his team want to find out how the African mole-rats sense the magnetic field and which regions of the brain process the signals. To do this, the researchers measure the activity of neurons in a brain region known as the hippocampus, which is very important for spatial orientation. This is where information is transferred from short-term memory to long-term memory – so the hippocampus is sort of the main memory of the brain.

PhD student Runita Shirdhankar investigates so-called place cells in the hippocampus and analyzes them. Each of these neurons or place cells is active at a specific position in the maze. "The question is whether the cells become active at a different point if we change the magnetic field only. Then we would know that the place cells are receiving information from another type of cell in the brain that processes the direction of the magnetic field. We are looking for these cells," explains Malkemper. When searching for these cells in other regions of the brain, Malkemper and his team make use of proteins that are expressed whenever a neuron is active. To make them visible, the researchers label them with fluorescent dyes and then make the brain transparent. Under the microscope, the neurons activated by the magnetic field then reveal themselves by their glow. "Initial results indicate that several regions are involved in the processing of magnetoreception, including the hippocampus and the superior colliculus in the midbrain. That's where information from different senses is integrated in other mammals," says Malkemper.

> **"The eyes are probably involved in sensing magnetic fields."**
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> *PASCAL MALKEMPER*

Cells with particles of iron

Starting from these areas, Malkemper and his team want to find the sensory cells – that is, the actual compass organ – that the African mole-rats use to sense a magnetic field. They are seeking cells that contain tiny magnetic particles of iron. These magnetic needles made of iron oxide, however, are only a few millionths of a millimeter in size. Thus, instead of looking for them directly, the researchers want to be led from the brain areas to the sensory cells. Dyes highlight the neurons and their processes. The researchers are aiming to follow the way through these circuits, from one neuron to the next, right to the origin of the magnetic signal – the magnetoreceptor cells. The team already has an initial indication of the location of the magnetoreception; temporarily anesthetizing the eyes also disrupts the magnetic sense. "So the eyes appear to somehow be involved in sensing magnetic fields," says Pascal Malkemper.

Once the sensory cells for the magnetic information have been found, the researchers want to investigate how they work and identify the genes that enable the perception of magnetic fields. These would also reveal to researchers how magnetoreception developed in mammals. It could also help us to better assess whether and how the electromagnetic fields in the modern, human-influenced, nature affect animals. And finally, the African mole-rats in Malkemper's lab could provide answers to the question: do primates, including we humans, also have an unconscious magnetic sense?

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