Snoozing
between Heaven and Earth

For humans, even a brief bout of sleepiness while driving can have fatal consequences. Frigatebirds, on the other hand, can snooze while cruising through the air without crashing to the ground. What's more, they generally get by on very little sleep during their long flights over the open ocean, which can last for days. A team of scientists working with **Niels Rattenborg** at the **Max Planck Institute for Ornithology** in Seewiesen has demonstrated for the first time that birds can fly in sleep mode.

TEXT **ELKE MAIER**

Photo: Niels Rattenborg

The bar-tailed godwit, a member of the sandpiper family, is one of the avian world's record-holders. It may not be as big as an ostrich, as fast as a peregrine or as loud as the South American oilbird, but when it comes to nonstop flying, it surpasses them all. This bird can cover a distance of over 11,000 kilometers from its breeding ground in Alaska back to New Zealand. It completes this entire journey in just eight days without any stopovers – no breaks to allow its muscles to recover, or simply to rest.

Impressive though this may be, godwits are far from topping the list when it comes to long-distance flying: frigatebirds remain in the air for over two months without interruption, and common swifts are able to fly for 300 days straight without landing. But how can these animals do this without any sleep at all?

Niels Rattenborg is Leader of the Avian Sleep Research Group at the Max Planck Institute for Ornithology in Seewiesen, south of Munich. An American with Danish roots, he has been work-

Nap in the nest: Two female frigatebirds recover from their latest hunting expeditions. In the background are the tents of the Seewiesen-based researchers.

Arriving on the island: For their research trip far from civilization, Niels Rattenborg and his colleagues must transport all essential supplies by boat. The sea lions aren't the least bit put off by the researchers' comings and goings (above). The female frigatebirds, such as this one being set free by biologist Bryson Voirin, also show little sign of shyness (below).

ing in this field for a good two decades. “Even as a child, I was fascinated by birds,” he explains. The fact that he ended up working on avian sleep owes to a vacation job: “During college, I worked in a sleep lab during the summer and over Christmas. I later worked there for ten years as a technician.”

As luck would have it, ornithology and sleep were easy to combine. Rattenborg studied biology, did his doctorate on the sleep behavior of mallard ducks and took up a position as a scientist in Wisconsin. He has been carrying out research in Seewiesen since 2005. He and his colleague Bryson Voirin have now provided proof that birds can actually sleep while flying.

FROM WORMS TO ELEPHANTS – EVERYONE HAS TO SLEEP

The question as to why organisms must sleep is one that has preoccupied scientists for generations. Whether we are talking about roundworms, fruit flies, fish, or elephants – no animal can get by for very long without sleep. Why this is the case is still not known. One attempt at providing an explanation is known in expert circles as the “synaptic homeostasis hypothesis.” According to this theory, the purpose of sleep is to clear the head: while we are awake, we are bombarded with huge amounts of information that need to be processed. To do this, new synapses are formed in the brain and existing connections expanded. “At some point, our heads would be so full that we wouldn’t be able to absorb anything new,” says Niels Rattenborg. To prevent this from happening, some connections are deleted while we sleep, generating new capacity.

The fact that the regions of the brain that have been very active during the day sleep particularly deeply at night supports this hypothesis. Niels Rattenborg and his colleagues observed this in pigeons: they showed them David Attenborough’s film *The Life of Birds* and kept them awake while the film was playing. Each bird had one eye covered during the film presentation. That night, the brain region responsible for the seeing eye slept more deeply than that associated with the covered eye.

But why do sleep requirements differ so widely across the animal kingdom? How is it that hedgehogs and bats sleep for up to 20 hours per day while giraffes can get by on just two hours? And what happens with birds that have no opportunity to make intermediate stops when flying over the open ocean? Do they sleep in the air? Do they refrain from sleeping temporarily? Or is it possible that their brains sleep in installments?

Rattenborg had already observed a fascinating phenomenon while doing his doctoral work on mallard ducks: in a group of sleeping ducks, those sitting at the edge kept their outwardly directed eye open and the corresponding brain hemisphere remained awake. In this way, the birds can rest a part of their brain while keeping an eye out for potential predators. Unihemispheric sleep, when only one half of the brain sleeps while the other remains awake, is found not only in birds, but also in dolphins, seals and manatees, for instance.

Other bird species, in contrast – such as the North American white-crowned sparrow – need far less sleep at certain times than they normally do. While their conspecifics in the wild travel to their wintering grounds, white-crowned sparrows in captivity jump restlessly around their cages and beat their wings. As Rattenborg and his colleagues discovered, during this period, known as migratory unrest, the birds sleep only one-third of the amount they would normally sleep. Surprisingly, the sleep deprivation appears to have no negative impact on the birds: they perform learning and memory tasks just as well.

YOU SNOOZE, YOU LOSE

The Arctic pectoral sandpiper also manages perfectly well with little sleep. Together with a team of researchers from Seewiesen, Rattenborg observed that the males don’t allow themselves to rest very much during the three-week mating season. Instead, they invest all their energy in engaging in skirmishes with other males and in wooing the females. Paternity analyses have shown that this strategy serves them well: the males that slept the least had the most offspring. “So sexual selection encourages short sleeping in pectoral sandpipers,” says Rattenborg.

To find out how flying birds manage their sleep requirement, Niels Rattenborg and his colleagues joined forces with neurophysiologist Alexei Vyssotski from Zurich. Vyssotski developed miniature data-logging devices that are so light that they can be carried by birds even when flying. The devices record the birds’ head movements and wing beats and simultaneously measure their brain activity. To do this, the researchers attach sensors to the animals’ heads to measure variations in the volt-

Photos: Bryson Voirin (top), Ryan Tisdale (bottom)

Idyllic island: While working in the field, the scientists exchange their fixed abode for a spacious tent (left). Niels Rattenborg heads off from the camp to check on the frigatebirds (right).

age generated by the brain. The sensors record the electrical activity of millions of neurons in the waking state and during the different sleep phases, and depict characteristic wave patterns on an electroencephalogram (EEG). This development enabled the scientists to study the waking and sleep behavior of flying birds for the first time.

As their research subject, they chose the great frigatebird (*Fregata minor*). This is one of the biggest seabirds, with a weight of up to 1.5 kilograms and a wingspan of over 2 meters. The measuring device, including batteries, weighs just 12 grams and presents no great burden for the animals when flying.

Frigatebirds spend most of their time in the air and are perfectly adapted to this lifestyle. They mostly sail above the oceans without beating their wings, watching for flying fish and squid that are driven to the surface of the water by dolphins and predatory fish.

In the water, however, these consummate flyers are relatively helpless. “Their plumage isn’t water-repellent and becomes completely saturated. They also have very small feet, which aren’t good for swimming,” says Rattenborg. So frigatebirds depend on being able to catch their prey from the air. During their lengthy hunting expeditions, they aren’t able to rest on the water like albatrosses, for example.

For their research on the frigatebirds, Rattenborg and Voirin collaborated with Sebastian Cruz, a seabird expert from Ecuador. Together they set up camp right next to a frigatebird colony on Genovesa, one of the small uninhabited islands in the Galapagos archipelago. “We had a kitchen tent and a laboratory tent to work in, and we slept under the open sky on hammocks,” reports Voirin.

FEMALES MAKE BETTER TEST SUBJECTS

In the interest of sleep research, the scientists themselves also went without sleep: they began by locating the nests during the day and then returned to them at night to catch the birds. In this way, they kept the disruption to a minimum. Fortunately, the animals build their nests on bushes at a maximum height of 2.5 meters, so the researchers were spared having to embark on nocturnal climbing adventures. As the birds in the Galapagos have no natural predators, they’re not timid around people and are thus easy to catch.

For their study, the researchers chose females as their test subjects. “Because they are bigger than the males, it’s easier for them to carry the logging devices,” says Rattenborg. “What’s more, unlike the more easily disturbed males, we had the certainty that the females will always return to their young.” With frigatebirds, both partners usually share the task of rearing the offspring. While one parent is off looking for food, the other one guards the nest against other members of their species who would be only too happy to swallow small, unguarded young birds.

In order to fit the logging devices onto the female birds, the scientists temporarily anesthetized them and took them to the laboratory. It took around 30 minutes to secure the devices to the birds’ heads and backs using a special glue and tape. In addition to the devices for measuring brain activity, head movements and wing beats, the researchers also fitted the birds with GPS loggers that recorded their locations and flight altitudes. Once they were fully equipped, the researchers returned the feathered test subjects to their nests.

It was then a question of waiting until the frigatebirds headed off to

hunt for food. “Once they had flown away, we checked the nests regularly so that we wouldn’t miss their arrival back home,” says Voirin. Fortunately, everything went according to plan: the birds had returned after no more than ten days. It later emerged that they had covered distances of up to 3,000 kilometers in the interim.

The scientists then had to catch the birds again to access the data. They were able to read the data loggers on site and obtained data from a total of 14 birds. Five of them had been on their travels for so long that the memory capacity of the recording devices ran out before they returned. With the other nine birds, the devices had continued to record when they were already back in their nests. The biologists were thus able to compare their sleep behavior in the air and on land.

Back in Seewiesen, Rattenborg studied the recorded EEG graphs. “When they’re awake, the amplitudes are small, but the frequencies are high,” explains the Max Planck researcher. This pattern is due to the fact that the neurons in the brain fire unsynchronized electrical signals. Other EEGs were produced during deep sleep and presented higher amplitudes and lower oscillation frequencies. In this state, the neurons synchronize and are alternately active and inactive, creating slowly oscillating brain waves. Deep sleep is thus also referred to as slow-wave sleep.

POWER NAPS REPLENISH ENERGY STORES

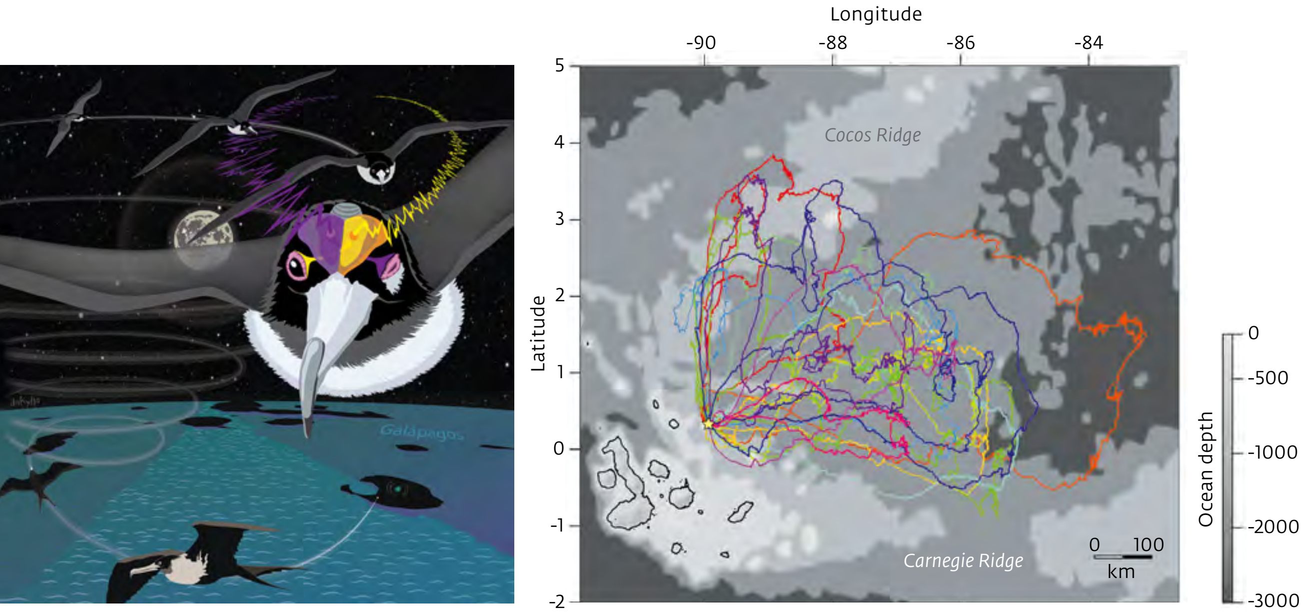
This kind of slow-wave sleep was evident on the EEGs recorded during flight. That was their proof: frigatebirds sleep while they fly and, to the scientists’ surprise, not only with half of the brain, but with both halves at the same time. “Even though they are able to fly when both halves of the brain are asleep, one side usually stays awake: the side associated with the eye that looks in the direction of flight. This is probably how the birds avoid collisions with other members of their species cruising through the same air stream.”

The animals usually doze in the early evening, shortly after sunset, when they are flying at a sufficient altitude and in a rising thermal – to protect them from falling. “This short sleep in the evening is probably a kind of power nap. It’s just enough to make up for the sleep deficit accumulated during the day.” During the day, the birds are wide awake and concentrate fully on searching for food.

In addition to slow-wave sleep, the logging devices occasionally recorded short episodes of REM (rapid eye movement) sleep. EEG graphs with low amplitudes and high frequencies, which also occur in wakeful birds, are typical of REM sleep. REM sleep always occurs in both brain hemispheres, and is present not only in birds, but also in mammals, including humans. In mammals, REM phases last up to one hour, during which muscle tone is completely lost and the body goes limp. In birds, in contrast, REM sleep lasts only a few seconds and, although their muscle tone also falls, they can still stand or fly.

The function of REM sleep remains a mystery. Researchers assume, however, that it plays an important role in normal brain development. This is supported by the fact that most young mammals spend longer in REM sleep than their adult counterparts. In newborn human babies, it accounts for more than half of total sleep time, while it takes up only a quarter of sleep time in adults. Niels Rattenborg and his team observed a very similar pattern in

Photos: Ryan Tisdale (left), Bryson Voirin (right)



Frigatebirds make use of rising thermals as they glide over the ocean in search of food. This activity demands their full concentration. They usually allow themselves a short nap after sunset. However, they keep the eye looking in the direction of flight open, and the corresponding brain hemisphere awake (left). GPS loggers enable the researchers to precisely track the flight routes. The birds cover distances of several hundred kilometers per day (right).

birds. In a study they carried out on young barn owls, they established that the proportion of REM sleep declines with age in owlets, as well.

Thus, both slow-wave and REM sleep occur in flying frigatebirds. They apparently don't need to keep one part of the brain awake to keep themselves in the air. Nevertheless, the birds allow themselves hardly any time for sleeping while flying. Over a 24-hour period, they slept on average for a total of just 42 minutes, and the average stretch of sleep lasted just 12 seconds. The longest uninterrupted stretch of sleep recorded was just under six minutes. On land, in contrast, the animals slept over 12 hours. These sleep phases were not only longer (52 seconds), but also deeper. It would therefore appear that the animals make up for lost sleep, just as we humans do.

In an earlier study, the researchers in Seewiesen had already demonstrated that pigeons compensate for sleep deficits in a similar way: when the scientists deprived their test subjects of their usual midday nap, they slept more intensively that night. Unlike the frigatebirds, however, the pigeons quickly became tired when they were kept awake for just a few hours. "We constantly had to gently remind them to stay awake."

WANTED: A MIRACLE CURE FOR FATIGUE

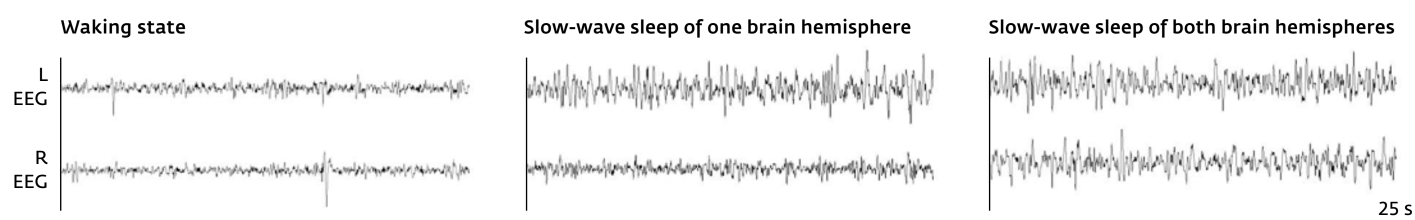
But why don't the frigatebirds sleep for longer in the air if, as it seems, they can do this without difficulty? "An earlier study showed that they follow favorable sea currents to locate abundant food sources," says Rattenborg. "It's possible that they also stay awake at night so they can observe the surface of the water and ensure they are in the right place for eating first thing in the morning." This obviously requires the full attention of both brain hemispheres; otherwise, the birds would probably sleep more.

How the frigatebirds compensate for the negative impacts of sleep deprivation is still a mystery. Nor do the scientists yet know why we humans find it almost impossible to suppress our sleep requirement. "Pigeons also get tired like people, but the frigatebirds simply carry on as usual!" The fact that humans and birds have developed very similar sleep patterns independently of each other gives the researchers hope that they will also learn something about human sleep from their avian sleep research findings.

Rattenborg even received a grant from the US military for his white-crowned sparrow project, but it didn't yield the miracle cure – enabling soldiers to withstand fatigue – for which they had likely secretly hoped. "Other occupational groups, such as rescue teams working in the aftermath of a natural disaster, would also benefit from such a substance," says Rattenborg. Wouldn't it also be helpful for him as a scientist to sleep less and be able to spend more time on his research? "Why not," he says, laughing.

In any case, his research has already contributed indirectly to new insights into human sleep. Inspired by his research on the mallard ducks, scientists recently discovered that, like the ducks on the edge of the group who keep the outwardly directed eye open, humans keep parts of one brain hemisphere

Graphic: Damond Kyllo/dakyllo Designs (left), MPI for Ornithology (right)



Above Flying light: The tiny measuring device on the birds' heads records their brain activity (above).

Below The EEGs show the waking state (left) and slow-wave sleep patterns for one (center) and both brain hemispheres (right).

awake when they sleep in an unfamiliar environment. "So there's reason to think that we will also learn something about our own sleep from the sleep behavior of the frigatebirds."

Rattenborg would now like to fit bar-tailed godwits with mobile logging devices and accompany them on their journey from Alaska to New Zealand. "Unlike frigatebirds, they actively beat their wings when they fly," says the Max Planck researcher. The question is whether they sleep while doing this. To determine this, the researchers must first develop even smaller and lighter logging devices, as bar-tailed godwits are considerably smaller than frigatebirds. ◂

Photo: Bryson Voirin; graphic: MPI for Ornithology

TO THE POINT

- **Frigatebirds can sleep in flight. When this occurs, usually only one of their brain hemispheres sleeps, but occasionally, both sides do.**
- **When in flight, the birds sleep for a total of only around 42 minutes per day. Each period of sleep lasts just 12 seconds on average.**
- **Their brains can go into slow-wave and REM sleep during flight. While the musculature of mammals becomes completely limp during REM sleep, birds can still glide through the air.**

GLOSSARY

REM sleep: Rapidly oscillating brain activity that is comparable to the waking state. Typical features of REM sleep are rapid eye movements and reduced muscle tone. The arousal threshold is very high and the majority of dreams occur during this phase in humans. Today, scientists think that REM sleep emerged at a very late stage in evolution and is present only in mammals and birds. However, there have recently been indications that some reptiles may also experience REM sleep.

Slow-wave sleep: Slow-wave sleep is the sleep phase with the highest arousal threshold, which explains its colloquial designation – deep sleep. Delta waves ("slow waves") with a frequency of less than four oscillations per second are characteristic of slow-wave sleep. These waves gradually spread through the entire brain. Thus, not all areas of the brain are in slow-wave sleep at the same time. The waves of activity probably play a role in the processing of information recorded by the brain while awake.