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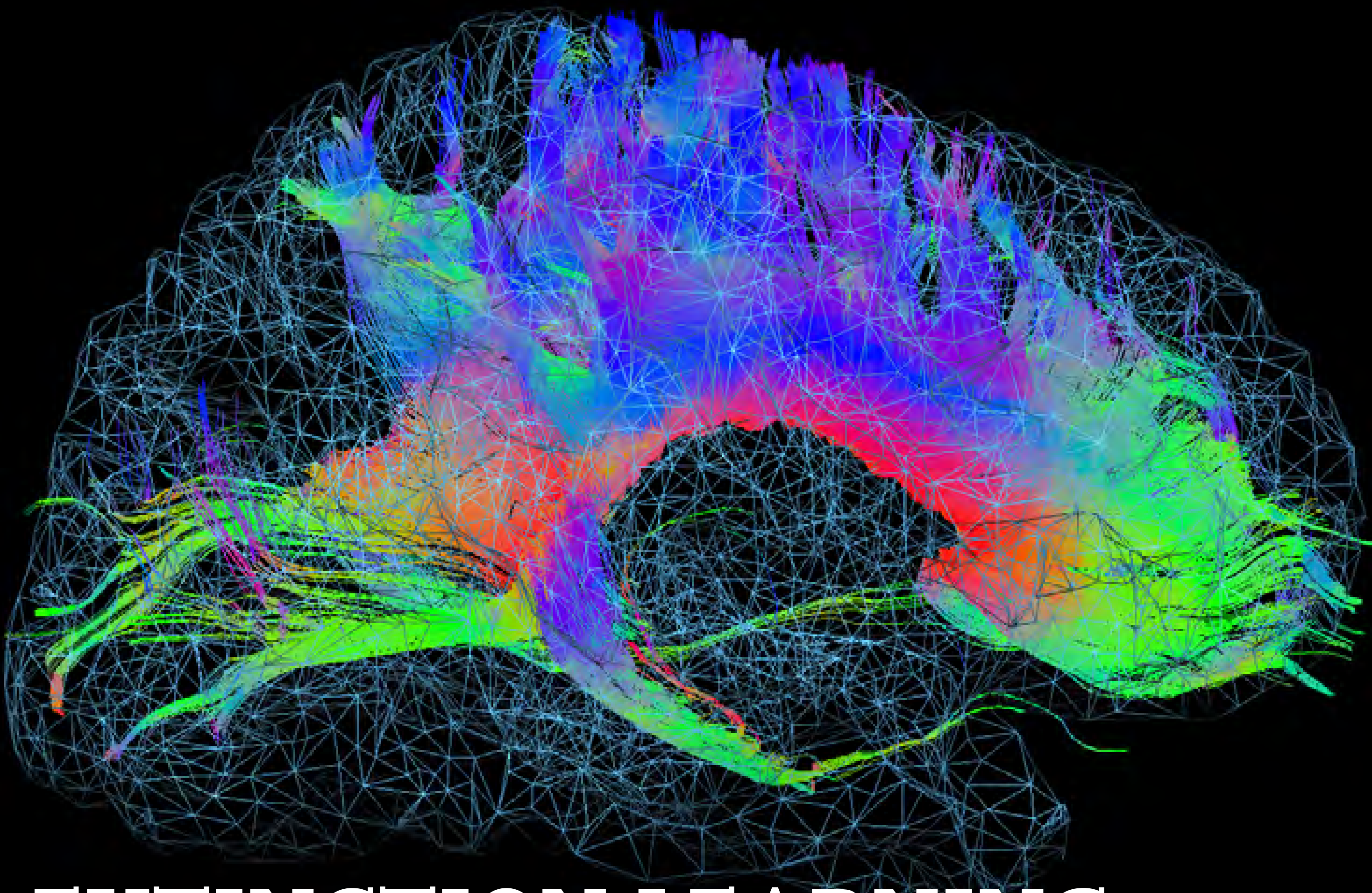
SPECIAL ISSUE



EXTINCTION LEARNING

What happens in the brain during learning

Why the context of an experience is crucial in this process

And how research into extinction learning helps patients overcome pain and anxiety

#35

Special Issue 2025:

SFB 1280 Extinction Learning

Biopsychology

A SMALL BUT **POWERFUL BRAIN**

Pigeons are intelligent, hard-working and evolutionarily far removed from humans. This combination makes them particularly interesting for the Bochum team's research. (photo: rs)

Pigeons are hard-working learners. And quite clever. A stroke of luck for the Bochum biopsychologists, who, thanks to them, are making advances into the fundamental mechanisms of extinction learning.

A yellow square lights up. Peck! The pigeon hits the glowing square with its beak. Shortly after, a flap at its feet opens up and releases a food pellet, which disappears into its beak in an instant. With the aid of rewards of this kind, pigeons quickly learn to associate the reaction to an actually neutral stimulus such as the illuminated square with a positive outcome. The Biopsychology research group at Ruhr University Bochum, however, is above all interested in what happens when the birds have to relearn, i.e. if the yellow square suddenly no longer results in a reward. The mechanisms of this extinction learning are the focus of Collaborative Research Center 1280.

Unlike in many other experiments, Bochum biopsychologists Dr. Roland Pusch and Professor Onur Güntürkün work with birds instead of mice, rats, or humans. "We are studying an animal whose last shared ancestor with these three species lived 324 million years ago: the pigeon," explains Onur Güntürkün. The reason for this is simple: Pusch and Güntürkün are searching for the fundamental components of extinction learning that should even be the same in species far distant from humans from an evolutionary perspective.

"Fear conditioning has been used for many studies with humans, rats, and mice," explains Roland Pusch. In these studies, animals and humans learn to associate a neutral stimulus with unpleasant consequences, such as a mild electric shock – and then to unlearn this association again. Such experiments are obvious, as reduced extinction learning ability following unpleasant experiences is central to anxiety disorders. But do studies of fear conditioning provide general information about extinction learning? Or are the results only specific to learning fear? Or possibly specific to the studied species? From reward-based studies with pigeons and comparisons with earlier work on other species, the Biopsychology team is hoping to gain general insights into extinction learning.

▶

Roland Pusch and Onur Güntürkün are looking into the general principles of extinction learning in Collaborative Research Center 1280. (photo: rs)

"There are pigeons wherever you find humans. They live right alongside us and no one would think that the perfect adaptation to identical habitats is possible with a brain that is organized completely differently," says Güntürkün. As a comparative cognitive neuroscientist, he is interested in the cognition of various animal species. "Birds have taken a different path to mammals in the evolution of their brains," he explains.

Comparable learning processes in pigeons and humans

The cerebral cortex, which makes up the majority of the human forebrain, developed in pigeons independently of mammals and is limited to areas that process sensory information. Most other areas are organized in an as yet unknown fashion and appear under the microscope to be a disorganized gray mass – i.e. completely different to the six-layered cerebral cortex of the mammalian brain. Despite these major differences, birds, and thus also pigeons, display comparable learning processes and functionality of extinction learning, as Pusch and Güntürkün showed in a series of experiments.

To do this, they taught the birds to peck at colored squares for a food reward. These experiments took place in behavioral boxes in which the animals were presented with various stimuli. Not all stimuli were linked to a food reward. By specifically switching off individual areas of the brain pharmacologically, the researchers were able to uncover their contribution to extinction learning. The comparative results were mixed: Some brain structures appeared to do exactly the same as is known in mammals, while other regions displayed altered functions. For example, the hippocampus in mammals learns the context, i.e. the surrounding stimuli, in which the extinction learning takes place. This is similar in birds, but the visual system is also specialized in this. "A large proportion of the principles is thus the same and has a long evolutionary history," summarizes Roland Pusch. "However, on the long evolutionary path that birds and mammals have taken separately, changes have also occurred. Nevertheless, it is astounding how similar the mechanisms still are after 324 million years."

Prediction error triggers new learning process

In a further experiment, the two researchers looked at the activity of individual neurons during learning. "For this experiment, the pigeons had to work extremely hard," says Roland Pusch. The animals first learned that pecking a certain visual stimulus results in a food reward. As soon as they achieved their learning criterion, the color of the context, i.e. the ambient lighting, changed from white to red. From that moment on, pecking on the previously rewarded visual stimulus no longer led to a food reward. The pigeons repeatedly pecked at the pattern in annoyance, but nothing happened. They gradually stopped reacting: Extinction learning took place.

Güntürkün and Pusch wanted to find out what happens in the brain in the moment in which the previously learned pattern of behavior no longer worked. The absence of reward after a previously correct action leads to what is known as a prediction error in the brain. This event signals to the brain that an expectation was not fulfilled and a new learning process should begin. The experiments showed that the prediction error changes various components of the previously learned behavior.

The researchers expanded their experiment. After the extinction learning was completed, they changed the ambient lighting back to the original color. The pigeons immediately displayed the learned pecking behavior again, although it was also not followed by a reward in this phase. The learned behavior was not forgotten and its reappearance took place exclusively in expectation of a reward. The analysis of neuron activity showed: Information about the context – i.e. the environment in which the learning took place – is mainly stored in a region of the brain called the hippocampus. This information is provided in a region in the frontal area of the pigeon brain. There, decisions are prepared and made depending on the expectation of reward in the respective test environment.

Evaluating individual neurons in the brain produces a detailed picture of the thought machinery, but remains restricted to small regions of the brain. To study the entire brain at work, Onur Güntürkün, together with Dr. Mehdi Behroozi, developed a system in which pigeons can carry out extinction learning in an MRI scanner. For the first time, they were able to visualize the process of extinction learning in the entire brain in a non-human animal with high spatial resolution. ▸

Always hard at work: In behavioral boxes like this, the animals learn that reactions to certain visual stimuli are associated with food rewards. (photo: RUB, Marquard)

Roland Pusch originally investigated the sensory systems of fish. He is now fascinated by pigeons as a research animal. (photo: RUB, Marquard)

IT ALL DEPENDS ON THE CONTEXT

Appropriate behavior depends on the context. What is appropriate in one situation may be completely inappropriate in another. But what exactly is context? Professor Jonas Rose and his team are investigating context with pigeons, crows and jackdaws in another sub-project of the Collaborative Research Center 1280. The group "Neural Basis of Learning" teaches pigeons certain behaviors that the animals later learn to abandon. This extinction learning depends on the context. In other words, the behavior is stopped only in the context of extinction, while in other contexts, the behavior occurs again – a phenomenon that is referred to as renewal.

"A context is intuitively understood as the surrounding of learning, for example a room or a certain background," says Jonas Rose. "However, our experiments have shown that any stimulus can become a context – even a small visual stimulus that is present during extinction learning." However, if this stimulus was minimally changed – for example, if it lit up a second later – the rules of learning change and the animals no longer perceive it as the context. This shows that context is learned and independent of the physical stimulus properties.

In further studies, Jonas Rose's team would like to find out more about context dependency, for example whether the social context also influences extinction learning. The group has been researching social communication and attention in jackdaws for some time. "These birds are very clever animals whose intelligence is comparable to that of higher mammals," says Rose.

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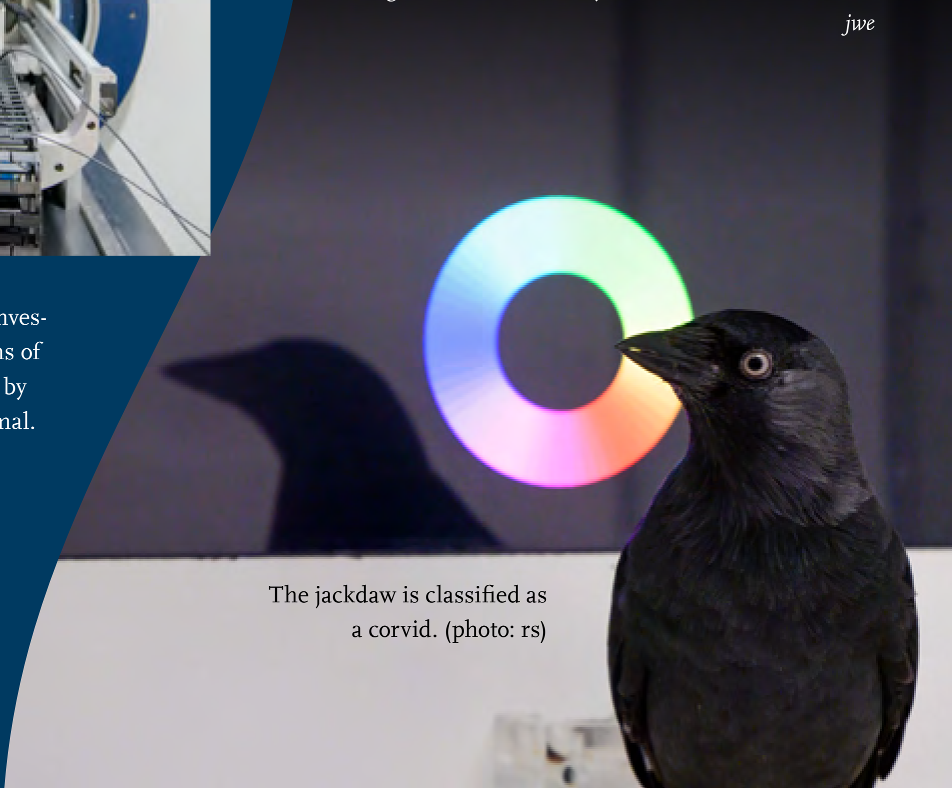

The jackdaw is classified as a corvid. (photo: rs)

As soon as extinction learning begins, activity is shut down in regions of the brain that process visual stimuli, which are important for the experiment. “The animal continues to perceive everything,” explains Güntürkün. “However, the processing pays less attention to these stimuli.” At the same time, limbic regions of the brain, which regulate emotional processes and are possibly connected to the animal’s surprise at not receiving a reward, despite believing it has done everything right, become active. In addition, the pigeon brain appears to go through a phase of restructuring its action program so that motor regions are activated. This makes sense, as the animal no longer has to react to the previously rewarded stimulus.

Common core of extinction learning

“Our studies show that there is a core of extinction learning that extends from humans to pigeons,” deduces Onur Güntürkün. “The most important trigger for extinction learning is the prediction error. It occurred in all species that have been studied so far. It is a wake-up signal that plows through most areas of the brain and gradually changes the way that the neurons react to changing conditions.” The regions that are changed in their coding processes are partly identical in birds and mammals. The prefrontal cortex for decision-making, the hippocampus for context memory, and the amygdala for emotion coding appear to be an indispensable trias that occurs in a similar way in these distant relatives.

“With functional MRI, it is now possible to study extinction learning in the entire brain of a non-human animal,” says Güntürkün. “Our results show that focusing on individual regions is not effective, as it only covers a small proportion of the processes in the brain. It is just as important to concentrate on how the processing changes in sensory areas, how the entire action processes are reconstructed, and how these changes are coordinated across large parts of the brain.”

Extinction learning comprises the largest part of the brain, and the prediction error leads to a massive change in the interaction between different areas. These insights are opening up approaches to developing therapeutic processes in many different areas for humans who are unable to find a way out of their anxiety because extinction learning is not functioning correctly for them. The Bochum pigeons will continue to help understand these processes – and earn even more delicious food pellets as they do so.

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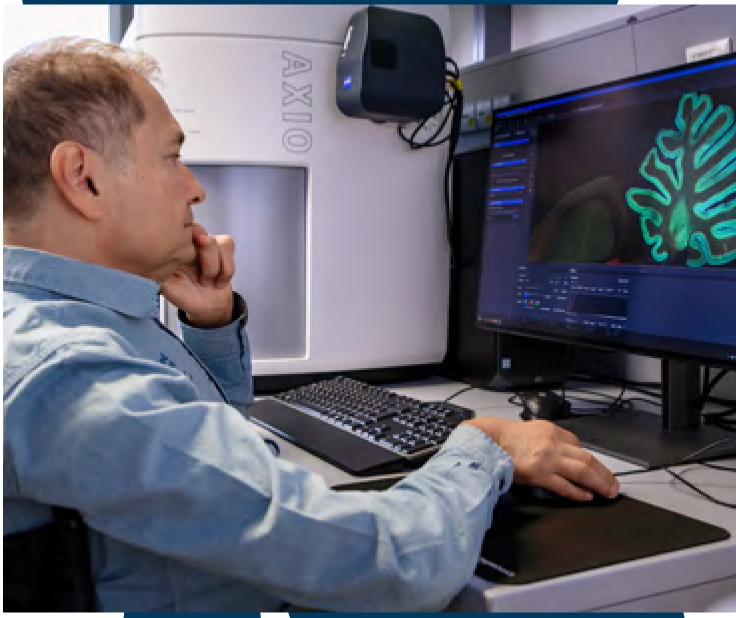
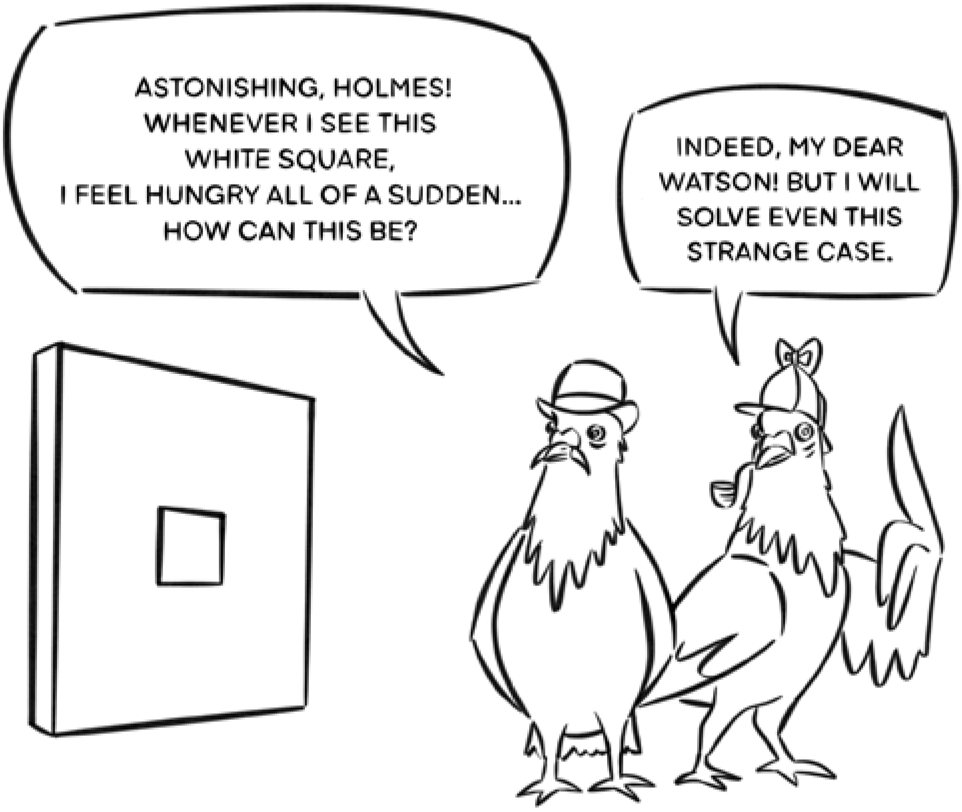
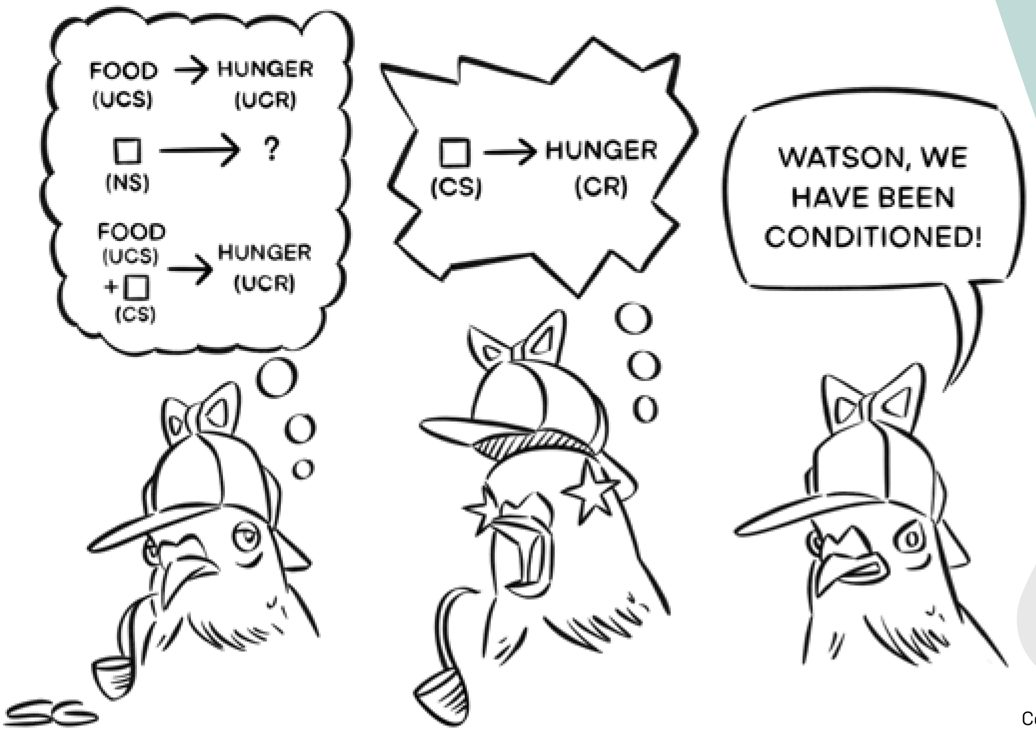
>
> Onur Güntürkün



A special feature of the Collaborative Research Center 1280 is that extinction learning is studied at all levels, from individual cells to behavior. (photo: rs)

EDITOR'S DEADLINE





UCS: unconditioned stimulus
NS: neutral stimulus
CS: conditioned stimulus
CR: conditioned response
UCR: unconditioned response

Comic: Simon Gies

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EDITORIAL BOARD: Dr. Lisa Bischoff (lb, editor-in-chief); Meike Drießen (md); Carina Huber (ch); Raffaela Römer (rr); Dr. Julia Weiler (jwe)

PHOTOGRAPHER: Roberto Schirdewahn (rs), Offerkämpe 5, 48163 Münster, Germany, phone: +49 172 4206216, post@people-fotograf.de, www.wasaufdieaugen.de

COVER: Prof. Dr. Erhan Genç

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