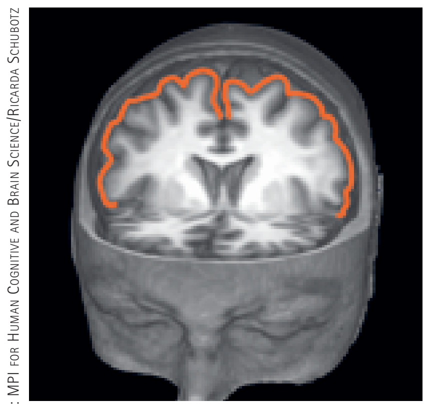
Illustration: Grossevision

Ultimately, the brain serves to direct us to act purposefully and expediently. To do this, sensory impressions and experience must be implemented as planned motor activities – via a switching point, the premotor cortex. **Ricarda Schubotz** *at the* **Max Planck Institute for Human Cognitive and Brain Science** *in Leipzig is researching its function.*

How the **Brain** Moves Us

Everyone knows those summer nights. It's wonderfully warm – ideal for sleeping in front of an open window and for drifting softly off to dreamland. But suddenly an all-too-familiar hum reaches our ears, promising nothing good. Surprisingly, as Ricarda Schubotz explains, "Although it is dark, and although we can only hear the sound of the mosquito, our brain can determine quite well where the mosquito is flying and where and when it has just landed."

To be more precise, a certain part of our brain – the premotor cortex, or PMC, for short – uses sensory information, whether hearing or seeing, to simulate the mosquito's movements. "A feat of genius," the neuroscientist finds. According to her theories, we use the premotor cortex to reenact, completely automatically and subconsciously, any kind of actions we observe, as long as they last no longer than a few seconds. For the young researcher, this region of the brain is a key switching point between the internal and the external world, "between what comes in through the senses and what I do with it in terms of the motor system." In that respect, the PMC functions as if it were the sensorimotor prophet of the brain.



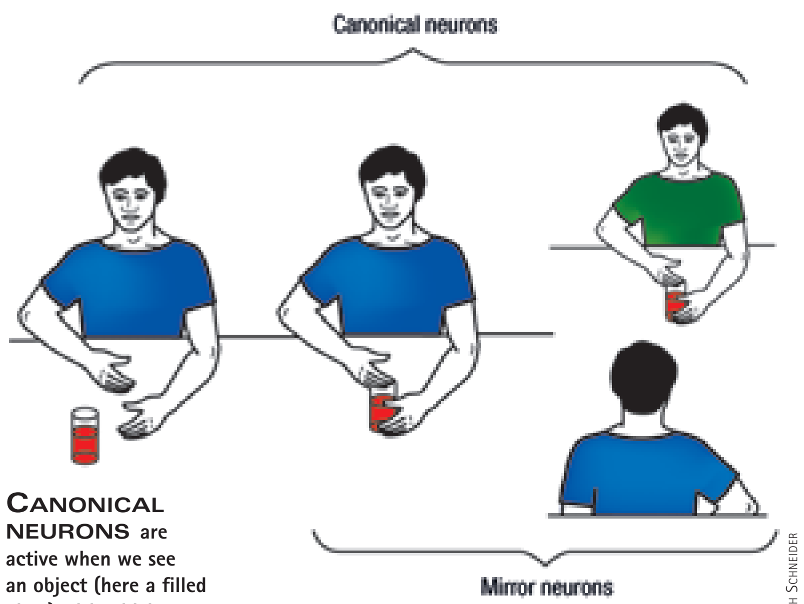
All figures: MPI for Human Cognitive and Brain Science/Ricarda Schubotz

A band of anticipation: As the hindmost province of the frontal lobe, the lateral premotor cortex (PMC) extends from the temples upward around the brain. Its immediate neighbor is the motor cortex.

The theory is based on Schubotz' experiments over the past few years and is quite provocative for the neuro scene. Previously, the premotor cortex was considered to be, first and foremost, the master of ceremonies when we are preparing to act. For example, we open a bottle with a corkscrew and pour the wine into a glass. Like thousands of other actions, we carry it out with hardly a thought, but it is a major feat for our brain. First, it must know that a corkscrew is needed to achieve the desired goal. Then the device must be positioned correctly – patients with a disease known as apraxia fumble around all over the bottle. Then the hand must push and turn the corkscrew and pull it out with a well-measured amount of strength.

"A rather complex sequence that, broken down into its individual components, comprises more than a hundred steps," says Ricarda Schubotz. And still the brain runs through the individual components amazingly quickly and smoothly – in the correct sequence, at the right time, all duly prepared and planned. So the PMC arranges the sequence of an action: ABCDEFG.

Anatomically, the premotor cortex, as the hindmost province of the frontal lobe, extends upward from the temples like a thin band around the brain – in the immediate vicinity of the motor cortex. Signals from the latter move down the spinal cord to the muscles that execute the movement. The latest neurophysiological studies on macaques indicate that Ricarda Schubotz' focus on the PMC puts her in an exciting field of research. According to these studies, the now famous mirror neurons are located in the PMC of these monkeys. These neurons fire not only when the animals perform a certain



Canonical neurons are active when we see an object (here a filled glass) with which we can perform an action. In contrast, mirror neurons – which scientists have so far detected only in monkeys, but suspect in a similar form in people, as well – fire when we observe the actual action, such as reaching for the glass, whether it is performed by us or by someone else.

action, but also when they observe the same action being performed by a conspecific.

Since their discovery, numerous new experiments have been launched, also involving people, and the mirror neurons have been linked to imitation, sympathy and such diseases as autism. A downright hype ensued over these cells. In people, however, the researchers speak only of a mirror system, as no one has yet been able to detect the neurons in the human PMC – although it is certainly possible to perform an appropriate search shortly before open-brain surgery on epilepsy patients.

Neurons for Pens and Paper Stacks

That is why Ricarda Schubotz warns against drawing analogies too quickly, and prefers to point out that several other fascinating types of neurons exist in the premotor cortex of monkeys – such as the canonical neurons. They fire when an animal touches or even just sees an object; it isn't necessary for any other monkey to reach for the object. However, unlike the mirror neurons, canonical neurons discharge only for object types that require a certain kind of grasp. A stack of paper for which the entire hand is needed to pick it up causes different cells to fire than, for example, a pen that can be picked up with a graceful move of the thumb and index finger.

So canonical cells rather represent a motor program – "how do I grasp something?" – than an object's shape or function. They are a sub-group of the so-called grasping neurons. For certain grasping neurons, it is irrelevant whether the monkey grasps something with its right hand, with its mouth or with its left hand – which entails a significant difference in terms of anatomy or musculature. What is far more important is that the object is grasped and brought toward the body. Sequence neurons are not specialized for simple movements, but rather for entire movement sequences. They can be easily detected in experiments with macaques: an automated food dispenser can be opened only by first pushing its control knob, then turning it, and finally, pulling it – a sequence that monkeys can learn in order to get at the food. However, the sequence of the three steps can vary from one experiment to the next. The sequence neurons react to the position of an action in the sequence – in other words, for example, they always fire upon the first movement, regardless of whether it is turning, pushing or pulling.

A Construction Kit of Neuron Tpyes

In monkeys, researchers observe various fields of the PMC that differ in how they are structured, how the cortical layers are arranged, or how densely packed the cells are. These fields differ not only anatomically, but also functionally. "What is interesting here," says Ricarda Schubotz, "is that it is not about how muscles or joints move, but rather how the creature manipulates an object on its body." The hypothesis is that, in the PMC, there is an entire array of representation options and a repertoire of action ideas. "I can grasp a cup to drink out of it, but I can also grasp it to clean it, to empty it out, or to give it to someone else," says the Leipzig-based neuroscientist.

So we have a construction kit of neuron types from which to assemble various actions. If a canonical neuron fires at the sight of a cup, the monkey need not necessarily want to reach for the cup. On the contrary: the animal may be participating in an experiment in which reaching for the cup is punished and watching the cup is rewarded. Seen this way, the PMC is not solely responsible for preparing actions. Why?

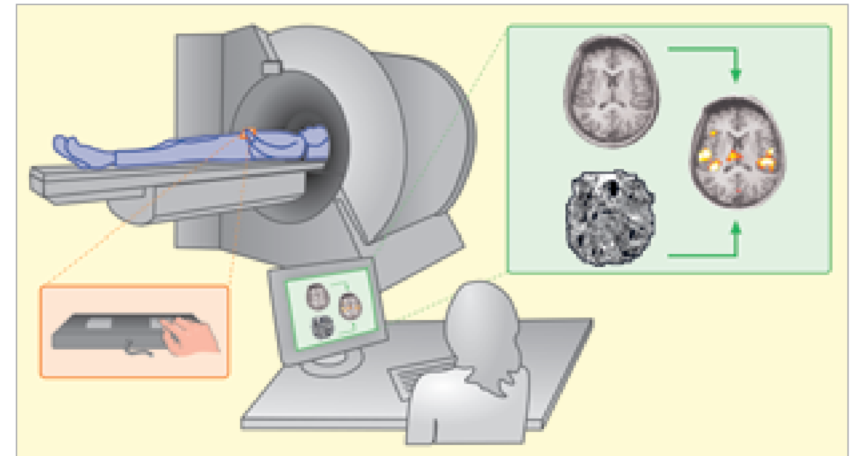
The scientists in Leipzig have long been searching for answers to this, also in people, using imaging methods such as functional magnetic resonance imaging. The principle behind this method sounds simple: while a test subject lying in the scanner performs a task, the tomograph identifies the brain regions that exhibit an increased metabolism – as an indirect measure of the firing neurons. Finally, colorful images show the relevant activation pattern. These studies of the premotor cortex revealed early on a parallel to the findings in monkeys: the PMC is active even when the experiment participants lie motionless in the scanner and work on a task without planning an action.

For the PMC to kick in without motor planning, two requirements must be met: on the one hand, the test subjects must be occupied with things that are associated with very specific everyday hand movements – with dishes, a computer mouse or tongs, for instance. "These objects have a pragmatic meaning for us," explains Ricarda Schubotz. When we see such objects, the premotor cortex links them, immediately, always and everywhere, with the appropriate action, so the hypothesis goes. This is because we register not only the shape, color, texture and orientation of such familiar things as a computer mouse, but also their significance for us as agents. The everyday association with these objects trains our corresponding perception, "in which even the potential action to or with them is contained," as the neuroscientist puts it.

Objects with Tactile Significance

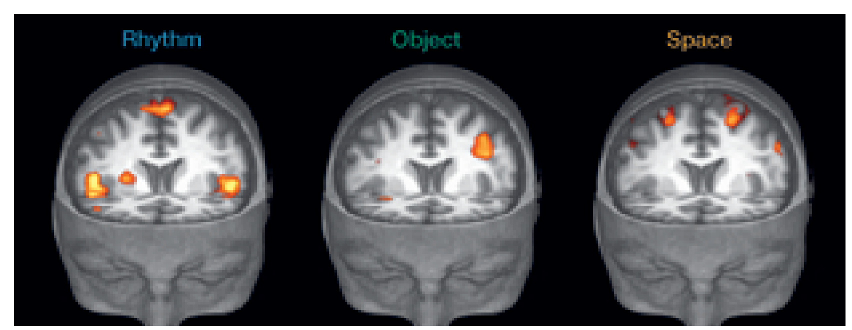
On the other hand, the PMC becomes active without motor planning also when the researchers assign the test subjects specific tasks in relation to an object presented to them. The look of the object is then irrelevant – they don't even have to remind us of real everyday objects. "What counts here is not what is seen," Schubotz emphasizes, "but rather what is to be done with them." Not only noticing abstract figures, but also noticing abstract sounds activates the PMC. "All of this is not immediately plausible," says Schubotz, and in explanation, brings anticipation into play. In short: all tasks that require perceptual events to be anticipated call the premotor cortex into the game. Even if no concrete action planning is required.

The Leipzig-based scientists shed light on this effect using what is known as the serial prediction task. For this, the test subjects in the magnetic resonance scanner see completely abstract stimulus sequences on a monitor. For example, two circles are presented that rotate in a certain manner around the center point of the screen. By expertly instructing the experiment subjects, they are brought to direct their attention to certain components of the movement: first to the circles themselves, second to the rhythm, or the temporal composition of the movement, and third to the spatial coordination of the movement. The question is: Are these different aspects represented separately in the PMC?



Insight into the Work of the Mind

Using functional magnetic resonance imaging (fMRI), the scientists examine which parts of the brain are active during a certain task. The subject lies in a tube in which a magnetic field is generated. Changes in the local metabolism in the brain can then be detected with radiowaves. When the test person performs tasks that require anticipation of perception events, the premotor cortex becomes active. These regions show up as colored areas on fMRI images.



Split anticipation: Different predictions activate different parts of the premotor cortex. As the fMRI images show, metabolism increases in different regions depending on whether we focus on rhythms, objects or space.

PHOTO: MAURITIUS IMAGES

Sometimes anticipation is vital – such as when we estimate the distance between us and other drivers on the street, and predict their movements.

The result: Whenever it comes to processing sequences, parts of the premotor cortex light up in the colorful brain images. For Schubotz, the reason for the PMC activation is obvious: every second, we have to coordinate our own actions with the events occurring around us. If, as pedestrians, we want to cross a street, we assess the moving cars and try to predict when they will reach us. We coordinate the time of our walking accordingly, or walk slower or faster. Moreover, we also anticipate effects that we want to achieve with our actions.

Where Planning and Anticipation Converge

There are multiple such action effects when we, for instance, pour wine into a glass: that we hold the neck of the bottle precisely over the glass, or that we do not cause the glass to overflow. "Action plans," says the researcher, summarizing a new hypothesis, "are primarily sequences of action effects, and not motor plans." We feel when we have gripped the bottle firmly enough to pick it up; we see when the glass is just full enough to set it back down.

So our brain actually anticipates two things: on the one hand, actions that we ourselves want to initiate, and on the other hand, events that other beings or physical forces cause in our immediate environment. Both forms of anticipation, as Schubotz' studies show, converge in the premotor cortex, allowing us to successfully take action. All tasks that require sequences to be processed activate the PMC – regardless of how abstract they are.

Action planning on the one hand, action anticipation on the other – do the two functions of the premotor cortex also go together anatomically? When people speak, and thus move their mouth, or grasp or reach for something, action planning causes different areas of the PMC to become active. In the broadest sense, this corresponds to the well-known homunculus – that strongly distorted representation of the body in the motor cortex, in which, say, arms, lips, hands or legs draw on defined areas of the brain in sequence. In the PMC, the body parts for motor planning overlap significantly and are represented multiple times, because actions typically entail moving several body parts simultaneously. Moreover, the overlaps are necessitated by the movement sequences that the PMC prepares and analyzes.

The studies by Ricarda Schubotz show that the body map for action anticipation in the premotor cortex is similar to that for action planning – depending on various stimulus characteristics of an object: What is it and what does it look like in terms of such properties as shape, color and structure? Where is it? And how long does the stimulus associated with it last? Certain pairs of motor planning and anticipatory functions do, indeed, correspond, because they each activate the same parts of the PMC: speaking – lip movements – and stimulus duration the lower area, hand movement and stimulus object the middle area, and arm movement and stimulus location the upper area.

Silently Singing Along with Familiar Melodies

"The various aspects activate precisely those regions in the PMC that address the appropriate body part for the given action," says Schubotz. If, for example, we anticipate a familiar melody we hear on the radio, the area of the PMC that controls singing movements automatically shifts into high gear. If, as we lie on the beach, our brain anticipates the arrival of an ocean wave, it activates – curiously enough – the same area. That is because waves hit the shore in a certain rhythmic pattern, and singing is first and foremost a highly rhythmic exercise.

"The premotor cortex is a platform that links sensory and motor functions," the scientist sums up. In terms of sensory functions, in the narrower sense, the premotor system serves our awareness. In other words, we must be prepared for a stimulus in order for the PMC to be activated – but then it will always be triggered, without us being able to consciously prevent it. Why planning and anticipation merge in the PMC is not yet clear. "But maybe," says Ricarda Schubotz, "we can gain our bearings in a constantly changing environment only if we can picture ourselves in everything that moves in a predictable way – as if we ourselves were causing the movement."

KLAUS WILHELM