Illustration: GrosseVision

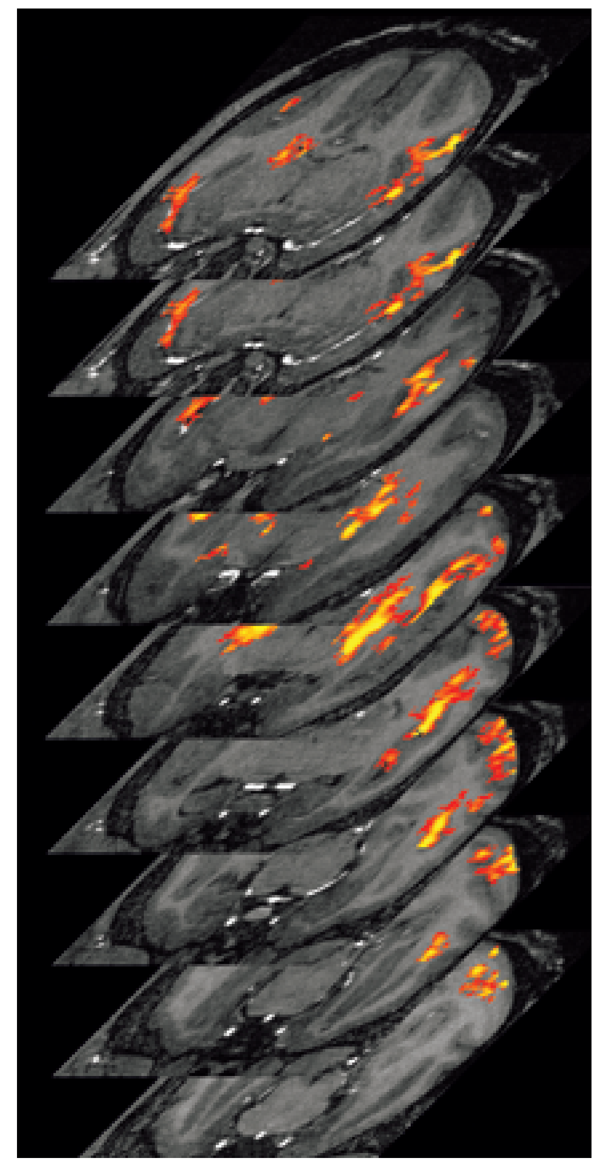
Our brain, more than anything else, determines what we hear. How it does that is a question that researchers in the Department for the Physiology of Cognitive Processes at the **Max Planck Institute for Biological Cybernetics** *in Tübingen are trying to answer. Led by* **Nikos K. Logothetis,** *the scientists study not only brain areas that are used for this, but also how the acoustic information is combined with the brain's impressions.*

The Eyes Hear, Too

Chaos reigns. I am on my way to the Max Planck Institute for Biological Cybernetics in Tübingen, where I have an appointment with Nikos K. Logothetis. But a sudden blast of winter has thrown rail traffic completely off schedule. Stuttgart's main train station is bursting at the seams with travelers desperately waiting for their connections. Everybody is talking at once, suitcases are rattling, groups of people hurry from one end of the station to the other, and loudspeakers continually drown out the general noise with announcements of the latest track changes.

It is acoustic mayhem – and the echo in the station building tops it all off. Nevertheless, I manage to pick out of the general jumble of sounds precisely the information I need to still get to Tübingen on time. And I even succeed in chatting with a fellow traveler at the same time.

Of course, in the commotion in the Stuttgart train station, I am not aware of just what a feat I – or better yet, my brain – is accomplishing. After all, it must process the extensive acoustic information making its way, unfiltered, to my ears. Ultimately, it also decides what portion of that reaches my awareness. How it does that is far from being fully understood. Another question that is largely open is how our brain links what is heard with what is seen or felt, and how it combines sensory stimuli into an overall picture of our surroundings.

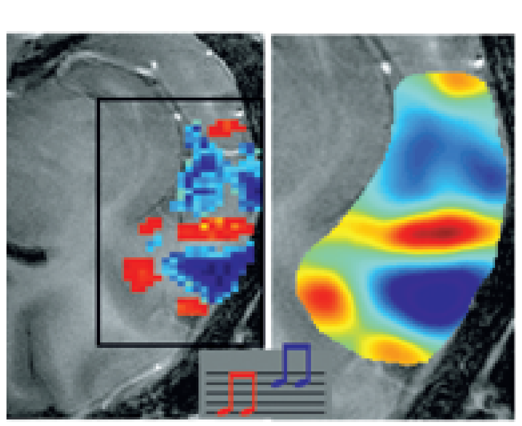


Surround sound: The stacked fMRI images show, in various cutting planes, the spatial distribution of a signal produced in the auditory cortex.

Photo: MPI for Biological Cybernetics

Where Sounds Find Their Place

"When we first became interested in these questions, I was really surprised at how little is known about the processing of acoustic signals," recalls Nikos K. Logothetis, Director of the Department of the Physiology of Cognitive Processes. Unlike with hearing, the brain's performance in terms of vision – in which the scientists were originally interested – has already been researched quite well. And he has an explanation for this: "Most people with hearing problems suffer a disturbance in the cochlea, not a defect in the brain." So researching the processes in the brain has always been of secondary importance – but not, in his opinion, any less interesting. ▶



PHOTOS AND DIAGRAM: MPI FOR BIOLOGICAL CYBERNETICS

High- (blue) and low- (red) frequency tones activate different parts of the auditory cortex. By comparing different frequencies, it is possible to allocate to each point on the image its preferred frequency and to compile a frequency map. With the aid of this map, and based on anatomical studies, the scientists can differentiate the individual areas of the hearing system (in the illustration, for example, A1 at the right stands for the primary auditory cortex).

Logothetis put the exploration of auditory perception in the hands of a young colleague: Christoph Kayser. The Max Planck researcher studied mathematics and theoretical physics at the Swiss Federal Institute of Technology (ETH) in Zurich. It was there, at a seminar at the Institute of Neuroinformatics, that he first came into contact with brain research – and got hooked. What stimulated – and continues to stimulate – him about the neurosciences is the interplay between analytical and experimental approaches. “The analytical approach that I acquired during my studies is very advantageous in dealing with the exciting and complex subject that is the brain,” he believes.

In the first step toward better understanding the brain’s hearing performance, Kayser and his American colleague Christopher Petkov created an exact map of the auditory cortex, which is located in the temporal lobe. Anatomic studies suggested that the auditory center – similar to what we already know from the visual center – is divided into multiple areas. To examine this in greater detail, Kayser and Petkov used functional magnetic resonance imaging (fMRI) to study the brains of rhesus monkeys.

How Seeing Influences Hearing

“These animals are fantastically suited for such analyses,” explains Petkov. “Their brain is very similar to that of people, and its anatomy has been studied very thoroughly in recent decades.” So the researchers can control whether the measured activities fit with the anatomical structure. “Furthermore, in the monkeys, we can check our findings at the electrophysiological level – in other words, by directly measuring the neuronal activity in the brain, which can’t be done in people.” To map the auditory cortex, the researchers played tones from different frequency ranges for the lab animals. At the same time, with fMRI, they essentially watched their brains at work. In doing so, they identified 11 different auditory fields, all of which represent the entire acoustic spectrum. To put it another way: in each of the individual regions, different groups of neurons are responsible for a different range of frequencies.

This suggests that the regions perform different tasks, like in the visual center. Here, too, an image that the retina registers is transmitted point for point in each individual area. And it is known that these fields take on different processing tasks. But while neuroscientists have some idea of what the various areas in the visual cortex do (some are responsible for spatial arrangement, others for color or more complex structures), hardly anything is known about the function of the individual auditory fields.

The map the Tübingen-based scientists drew of the auditory center now serves as a basis for finding out what role the individual regions play and how they interact. And whether they are, perhaps, influenced by other sensory stimuli. After all, our perception of our surroundings comprises information from different sensory organs. For example, the brain must link what we hear and what we see in order for us to properly and reliably register acoustic information. Good ventriloquists teach us what can happen when this doesn’t quite succeed – when the eyes and ears transmit information that doesn’t quite match: we hear a voice, see the doll’s mouth moving, and it appears as if the lifeless thing could actually speak. The artist has tricked our brain.

So the information that various sensory organs transmit is linked in the brain. The question is where, when and how that happens. Theoretically, there are many possibilities. One popular hypothesis is that the linking occurs last – that is, when each brain center already has a complete picture of its stimulus. The other extreme would be that the integration happens at the very beginning, in the first phases of sensory processing, and the senses complement one another. “We discovered something that suggests that the second hypothesis is more likely to be accurate,” reports Kayser. Together with his colleague Petkov, he observed that the work of the auditory center is influenced by visual stimuli.

For their lab animals, the researchers played sounds that occur in the natural environment of their conspecifics living in the wild, so for example, the rustling of leaves. As could be expected, the auditory cortex reacted to the stimulus, which showed in the fMRI through increased activity in this brain region. If the researchers then simultaneously showed the monkeys short film sequences in which animals were running through bushes, the auditory center became even more active. But that’s not all: even films with no acoustic background made a mark in this region of the brain, in the form of slightly increased activity signals. Videos that showed only colorful, complex structures rather than natural objects left no mark in the hearing region of the monkeys’ brains.

Intuition for the Ears

“This shows that sensory stimuli are obviously merged in this region, and that this happens right after the information arrives in the brain,” says Christoph Kayser, explaining the significance of the experimental results. What he and his colleagues see with the help of modern imaging methods in rhesus monkeys fits exceptionally with a range of observations that other scientists have made with people.

For example, the group working with Gemma Calvert at Oxford University in 2001 discovered that acoustic and optical signals amplify each other in speech perception. The sight of a speaker and his lip movements is sufficient to put the volunteer subject’s auditory cortex on alert – even if the actor is merely babbling unrelated, made-up sounds. If, however, the face on the monitor only makes silly faces, the auditory center is apparently left completely cold.

But it seems that not all regions in the auditory center react to what is seen. The researchers determined that only the areas in the caudal region – the end of the auditory center facing the back of the head – respond to optical signals with increased activity. “At the same time, this also shows the division of labor that takes place in the brain,” says Kayser. And it provides some clues about the importance of this sensory link. For example, it is known that many neurons in precisely these regions of the auditory cortex specialize in processing the spatial position of a sound source. This suggests that visual information in these regions could be used to analyze the spatial aspect of the acoustic signals in greater detail.

The regions in the back of the auditory center, however, are not only accessible to optical stimuli. They also react to sensorimotor information – in other words, what our sense of touch tells us. That is what the Tübingen-based researchers discovered in a further experiment: they played a noise for their monkeys and, at the same time, stimulated the tactile cells in the animals’ hands and feet with an electric brush, similar to those used to clean bottles.

Here, too, the additional stimulus did indeed amplify the activity in the back of the auditory cortex. At first glance, it may seem strange that touch stimuli should influence acoustic processing in the brain. From the researchers’ perspective, however, this is entirely reasonable: “Imagine that you are standing in front of your car in the dark and you are looking for the key you just dropped. You will be quite happy if you are able to com-

When the macaques in the experiment watch wild conspecifics in their natural environment (in the image, animals in Sri Lanka), activity in the auditory cortex increases.

PHOTO: SPL – AGENTUR FOCUS

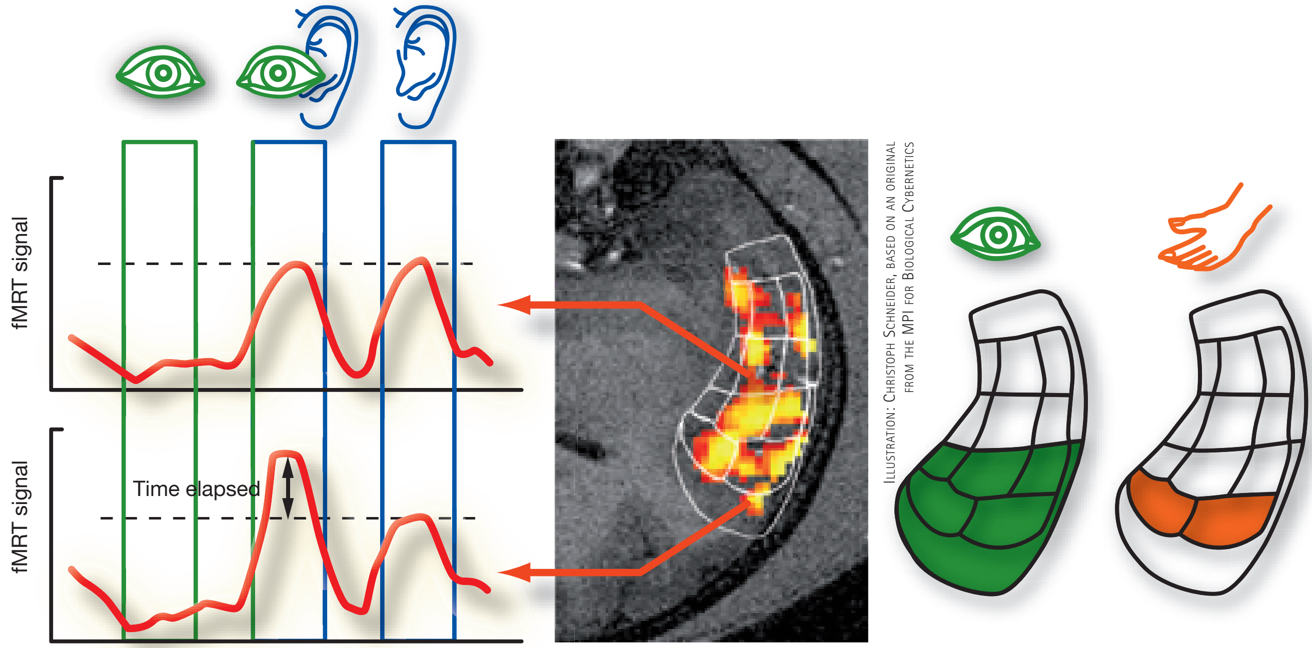


ILLUSTRATION: CHRISTOPH SCHNEIDER, BASED ON AN ORIGINAL FROM THE MPI FOR BIOLOGICAL CYBERNETICS

In one region of the auditory cortex (center image) the activation for auditory and audio-visual signals is identical (fMRI signal above left); in the other region, the activation is stronger for the audio-visual stimulus (fMRI signal below left, black arrow). Sensory integration takes place in this region. The outline at right shows the areas in the auditory cortex that are influenced by visual or tactile stimuli.

bine the remaining sensory stimuli," says Christoph Kayser.

So optical, acoustic and sensorimotor senses collaborate very closely to record as realistic and complete a picture of our surroundings as possible. And the findings from the lab in Tübingen suggest that the requisite link in the brain is created very early on, and not only after each individual stimulus has been analyzed. But should the auditory cortex, of all things, play a special role when it comes to linking sensory stimuli? Presumably not. "We could very naively assume that there are systems for linking the senses in all of the brain's sensory centers," says Kayser. At present, however, it is by no means certain that that is, in fact, the case. It is also conceivable that one specific sensory system particularly stands out. In humans and apes, though, it would more likely be the visual system, since the visual stimuli also have the strongest influence on the other sensory systems.

As early as 2000, researchers working with John Driver at University College London had already observed a connection between feeling and seeing. In their test subjects, activity in the visual cortex increased not only when the study participants saw a bright flash of light in the immediate vicinity of their hand, but also when they simultaneously felt a vibration near the fingers of that hand.

ALL SENSES LINKED TOGETHER

It remains unclear what concrete advantage we gain from optical and sensorimotor signals increasing the activity in the center of acoustic perception. Does it really help us hear better? Or grasp a situation more quickly? "We can't yet answer such questions with certainty," says Kayser, and adds: "Because, unfortunately, the fact that we measure a signal says nothing about its function." It is hoped that future experiments will reveal just what underlies the links between hearing, seeing and feeling.

The scientists certainly have enough ideas about what purpose the integration serves. Not only might the interplay between optics and acoustics help to better localize the spatial origin of a noise, but speech understanding may benefit from it, as well. Anyone who has ever been at a loud party knows that we can understand the person talking to us far better if we can also see their lip movements. "This means that our brain combines the acoustic and the visual speech stimuli. And it seems obvious, of course, that this should happen in regions of the auditory cortex," says Logothetis. But that is another story that the researchers in Nikos K. Logothetis' department are examining.

Impressed, I make my way home, thinking about what I learned in Tübingen. Pandemonium is still the order of the day at Stuttgart's train station. And I've missed my train back home. But when I ask at the information desk about the next connection, I notice something: amid all the noise around me, I can, indeed, better understand the explanations of the lady behind the counter if I look at her. STEFANIE REINBERGER