Under the hood: EEG measurements are used to monitor changes in brain activity when playing the piano, such as when the player is presented with musical challenges.

PHOTO: FELIX BERNOULLY/MPI FOR EMPIRICAL AESTHETICS

MUSIC IN YOUR HEAD

TEXT: STEFANIE REINBERGER

Music is an innate human ability. It is genetically programmed into our brains and, like language, it is a universal feature that we all share. The human mind is designed to both enjoy and create music. Together with her team at the Max Planck Institute for Empirical Aesthetics, Daniela Sammler is researching what exactly happens in our heads when we make music.

Humans have been making music for thousands of years. While exploring caves in the Swabian Alb mountains, archaeologists discovered bone flutes that were carved and played by Stone Age man around 35,000 years ago. These flutes are considered to be the oldest musical instruments ever found. However, we can assume that music already played a role in human evolution long before they were made. At the same time, it is highly likely that music is not simply an evolutionary by-product that developed from language, as researchers thought for many years. Instead, it appears to be a kind of sister to language, with these two means of communication originating from one shared early predecessor. This is reflected in the structure of the brain, which uses some of the same regions to process language and music.

Such similarities between language and music are a major topic of interest for Daniela Sammler and her Research Group at the Max Planck Institute for Empirical Aesthetics. Among other things, they also want to find out in which areas language and music are subject to similar mechanisms, and when the brain draws on different solutions in order to process these two forms of expression. Even before she began her research in Frankfurt, Sammler was exploring the way we listen to music, in collaboration with Stefan Koelsch and Angela Friederici at the Max Planck Institute for Human Cognitive and Brain Sciences in Leipzig. One of the key questions was how we perceive harmonies as well as disharmonies. In a similar way to grammar, music follows certain rules, which affect the way music is heard. We imbibe the musical rules of our cultural environment and intuitively apply them when we listen to music. For example, there are harmony sequences that appear to be "right" in our brains, and others that contradict this set of rules. In their experiments, the researchers did in fact succeed in demonstrating that the brain alters its activity in response to music that breaks the rules, such as "incorrect" final chords. "Interestingly, the brain's reaction to disharmonies is comparable to the way we observe grammatical errors in language," says Sammler.

However, hearing music is just one side of the coin. Music is made when we play it, when people sing, drum or press the keys on a piano. "We therefore wanted to find out if these rules also influence people who produce music as an everyday activity," Sammler explains. Making music involves two components. First, there is a musical idea – in other words, the concept of how music should sound and which harmonies we consider appropriate; then, we put this idea into practice using movement – such as placing our fingers on a piano keyboard, covering certain holes on a flute, or moving our larynx and vocal cords when we sing.

Here, therefore, cognition and motor activity combine and mutually influence each other. This corresponds to the theory of "embodiment", which has attracted a great deal of interest, and which states that the body and mind work together. According to the theory, motor functions are not just the result of cognitive processes – instead, they themselves also support cognition. To take a simple example: children use their fingers when learning to count. According to the theory, the movement of a certain number of fingers supports the concept of counting in the brain. Pianists put a musical idea into practice by positioning their fingers on the keyboard and striking the keys. While they do so, the movement of their hands and fingers follows the grammatical rules of music. Conversely, the motor activity reinforces the musical idea – in other words, the notion of how the music should sound. Indeed, there is a great deal of evidence that indicates that among musicians, the auditory and motor systems are closely linked to each other.

However, playing the piano involves more than just hitting the right keys. In theory, a chord on the piano keyboard can be played using a wide range of different hand and finger movements. In practice, the choice of fingers used additionally depends on efficiency factors, such as how quickly a chord can be played with a particular fingering, and how the player can best move on from there to the next chord. A further aspect is the feeling that the player wishes to express. The player's thumb has more strength than their ring finger, for example, and this has an impact on the volume. When making music, pianists therefore coordinate at least two planning levels: which chord, i.e. what notes they need to play in order to implement the set of musical rules in their head, and what fingering they should use to create the chord.

SUMMARY

People absorb the musical rules of their culture and intuitively apply them, in a similar way to the grammar used in their native language.

Measurements of brain activity among pianists show that they respond to both non-observance of harmony rules and "incorrect" fingering. Both are processed separately in the brain.

When making music together, musicians' brainwaves synchronize. This is evidently done in order to coordinate their playing.

To find out what makes this possible, Sammler and her team used electroencephalogram (EEG) measurements to observe the brain activities of pianists while they were playing. All participants had received at least ten years of training in classical piano. Their task was now to play harmonic sequences that they had not practiced, in line with hand movements on a screen. "We consciously avoided allowing them to play from sheet music, since that would have set other processes in motion that would have made it very difficult for us to control the experiment. For example, not everyone is equally proficient at reading sheet music," Sammler explains. "As my choir leader used to say: you need to learn the notes by heart so that you can concentrate on the music and the way you sound together, and not on the score in front of you."

A final chord – with a stumbling block

The sequences given to the pianists to play in the experiment were all musically "correct". However, the final chord was sometimes fitting, and sometimes contained an error. This error either took the form of an "incorrect" harmony, in other words, a grammar error, or an unusual set of fingering which a practiced pianist would not use, since it is difficult to realize. How would the brains of the test subjects respond to the errors? Both types of error caused changes in the EEG, such as a delay in playing. However, it emerged that errors in the fingering always caused a delay. By contrast, errors in the harmony interfered particularly in cases when the musicians had understood the idea of the sequence – in other words, when after a few chords, they had developed a sense of how the music should continue. According to Sammler: "This demonstrates that in fact, our musical brain separates the two planning levels – 'what is being played?', and 'how should I play it?'."

However, she didn't want to stop there. "In the EEG, we can only identify that the brain activities change, but not where these processes occur. For that, we need MRI – Magnetic Resonance Imaging." Together with a group of colleagues and the Blüthner pianoforte factory in Leipzig, she designed an unusual experiment. She sent pianists into the MRI tube, together with their pianos. To make this possible, she ordered a kind of mini-piano to be made, which had just 27 keys, and which the test subjects were able to play lying on their back in the scanner. A two-way mirror enabled them to see their own hands on the keyboard, and at the same time, see the hands showing them how to play the chords on a monitor, as in the previous experiment. Once again, the task was to play short sequences, some of which contained either a harmonic error or an error in the fingering at the end.

This confirmed what the researchers had already concluded from previous experiments: the two planning stages – the what and the how – ran their course separately from each other. They activated different neuronal networks in the brain. In the main, regions in the brain responsible for motor activity were used to coordinate finger movement, while planning the musical idea mostly activated regions in the frontal and temporal lobes, which are thought by scientists to act as memory sites for learned sets of rules. "However, the most exciting thing was that Broca's area was active during both challenges. Many people only think of this region in the brain as being the speech center. However, it also plays a role when planning an activity, regardless of whether we're formulating a sentence, brewing a coffee or wanting to make music," Sammler explains.

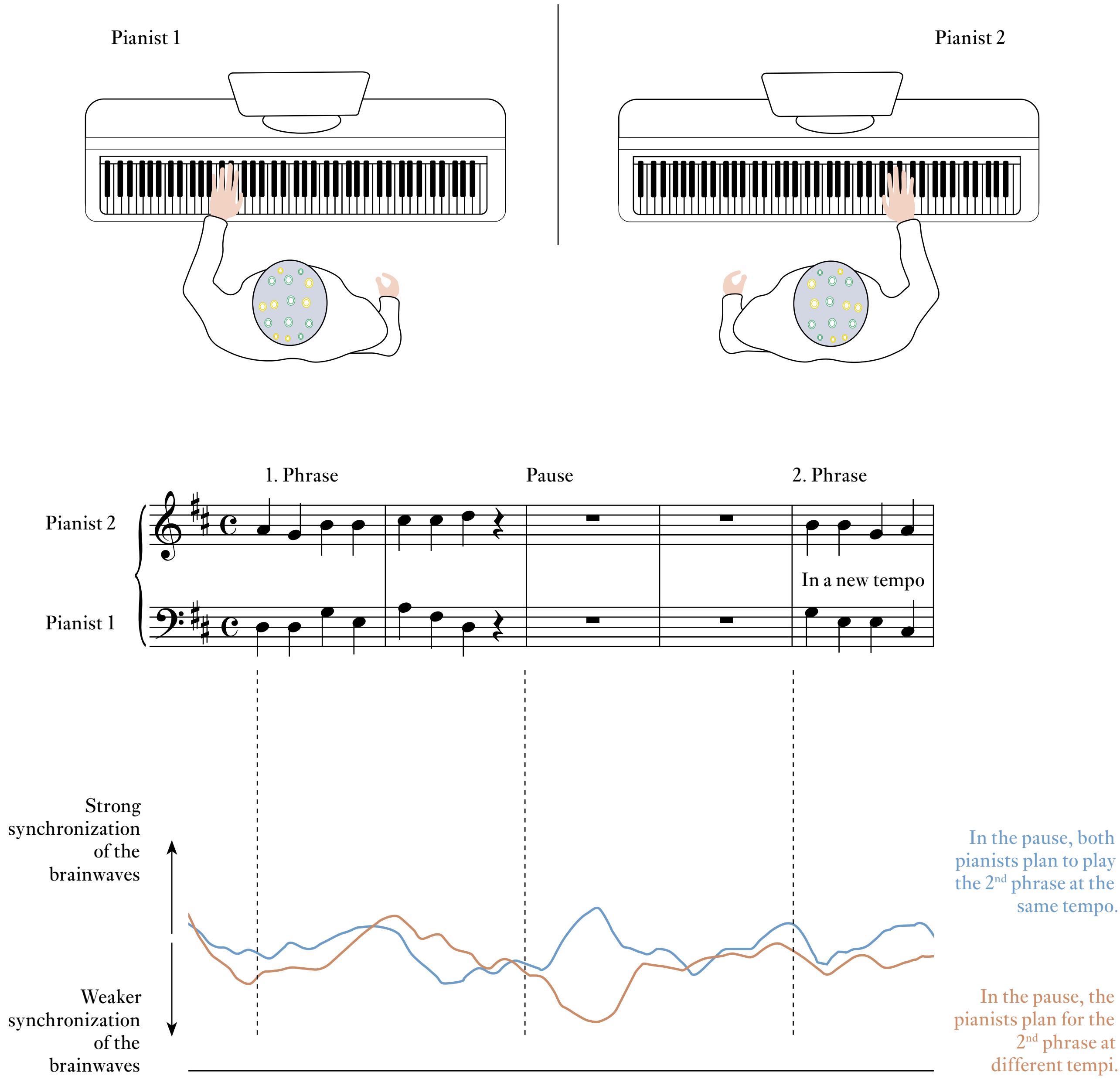
Research on this area of the brain has brought to light new evidence of how the brain plans activities. It shows that the idea occurs first, such as "talk about something", "brew a cup of coffee", or "play a melody". The front portion of the brain region converts this idea into rules of behavior: what activity steps are needed to brew the coffee? The planning then becomes increasingly intricate inside Broca's area, running from front to back from an anatomical perspective. For example: how should I put the coffee into the machine to get the correct dose? "We can also observe this pattern when making music: the planning begins with the musical idea and becomes more and more intricate, right down to the specific movement of the fingers on the piano keyboard," Sammler explains. Planning movements when making music therefore works in exactly the same way as everyday activities. There is a translation from the "what" to the "how" – from the musical idea to the movement on the piano.

PHOTOS: MPI FOR HUMAN COGNITIVE AND BRAIN SCIENCES (2)

Custom built: a mini-piano built specially for the experiment enables researchers to study a pianist playing in an MRI scanner. This allows the researchers to understand which areas of the brain are particularly active when we make music.

As exciting as these findings are, they focus solely on solo performance, in other words, on what happens to an individual musician when they play their instrument. "Basically, this is a very reduced situation," Daniela Sammler explains. "After all, from an evolutionary biology perspective, music was very likely something that people made together in the group." Concerts in which individual musicians play for an audience are a relatively new invention, however. Music was originally designed to promote a sense of togetherness, such as the communication between a mother and her baby, or when looking for a partner, or to promote a feeling of belonging in a group. While studies of

⟶



Synchronization test: two pianists play at the same time, initially at the same tempo. After a pause, they are told to change the tempo. The instructions given to each player are either the same or different. As a result, the synchronization of the brainwaves increases if the instructions given at the start of the pause are the same. By contrast, they deviate if the instructions differ. Scientists are still not exactly sure why the previous synchronization level is already achieved during the pause.

IMAGE: GCO, ACCORDING TO A SUBMITTED ARTICLE FROM GCO CEREBRAL CORTEX, BHAB469

individual test subjects provide insights into the fundamental principles of how our brains work, this is ultimately just one small aspect of the overall picture, and possibly a very limited one. “This applies not only to music, but to all activities in which people interact in pairs or groups,” says Sammler. “The Finnish neuroscientist Riitta Hari even went so far as to say that brains are designed primarily for interaction.”

Interaction is therefore at the center of cognition. However, very little is understood yet about how it works at the neuronal level. What we do know is that brains begin to oscillate in the same rhythm when people interact with each other. This phenomenon appears on the EEG in the form of synchronized brainwaves, and is something that occurs during all activities, from taking a walk together, dancing, debating with each other or

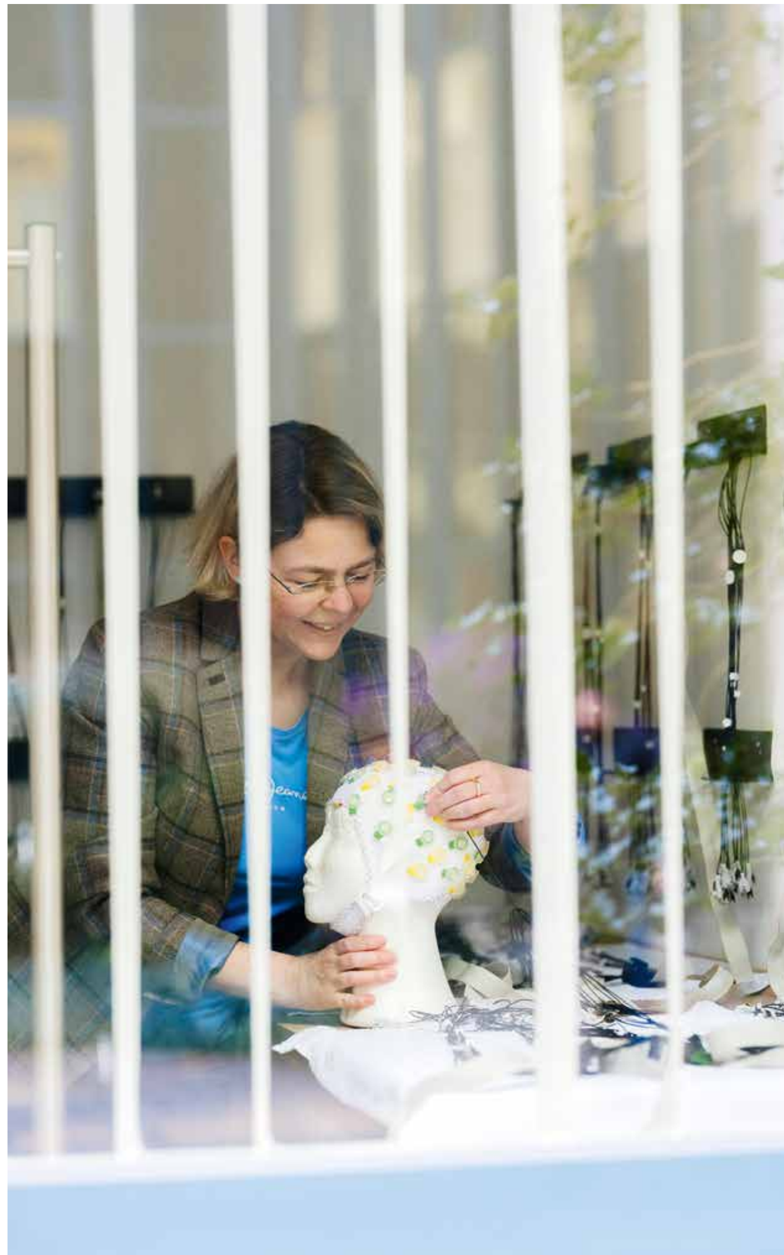


PHOTO: KATRIN BINNER

Carefully prepared: Research Group Leader Daniela Sammler prepares an EEG hood for an experiment with a pianist.

making music. However, do the brainwaves synchronize because we move in the same rhythm, for example, or play the same melody? Is the effect a result of us doing similar things at the same time? Or is it a mechanism that supports interaction?

A key factor for making music together

To examine this issue in more detail, Daniela Sammler and her team again conducted experiments on pianists – but this time, the test subjects played a duet. Each time, two volunteers were asked to play a melody together while the researchers recorded their brainwaves on the EEG. During the experiment, one person played the part for the left hand and the other played the part for the right hand. The harmonic progression and tempo were predefined in advance and matched each other – until there was a pause in the piece. Then, the musicians were instructed to continue playing at a different tempo, while each were given contrary instructions. This in turn influenced the synchronicity of their brains. If both planned with the same instruction – to play faster or slower – the level of synchronicity was high. However, if different tempi were specified, the brainwaves deviated from each other. The degree to which this happened depended on how much the planned tempi differed from each other after the pause.

"Our interpretation of this result is that synchronization of the brainwaves is not simply a by-product of playing together, but that it's a mechanism that enables musicians to coordinate their interplay," Daniela Sammler explains. "This probably doesn't just apply to music, but also to other activities for which good interaction is necessary." In other words, general mechanisms of interpersonal cooperation. The research being conducted by Sammler in Frankfurt may currently only provide information about the key importance of synchronization when people play music together. As it stands, noone can say where this synchronization originates in the brain. "To answer that question, we would need to put both pianists into different MRI scanners at the same time," Sammler says. She admits that this would present a big logistical challenge, of course. But she is very confident that they will manage it one day. "That experiment is yet to come!"