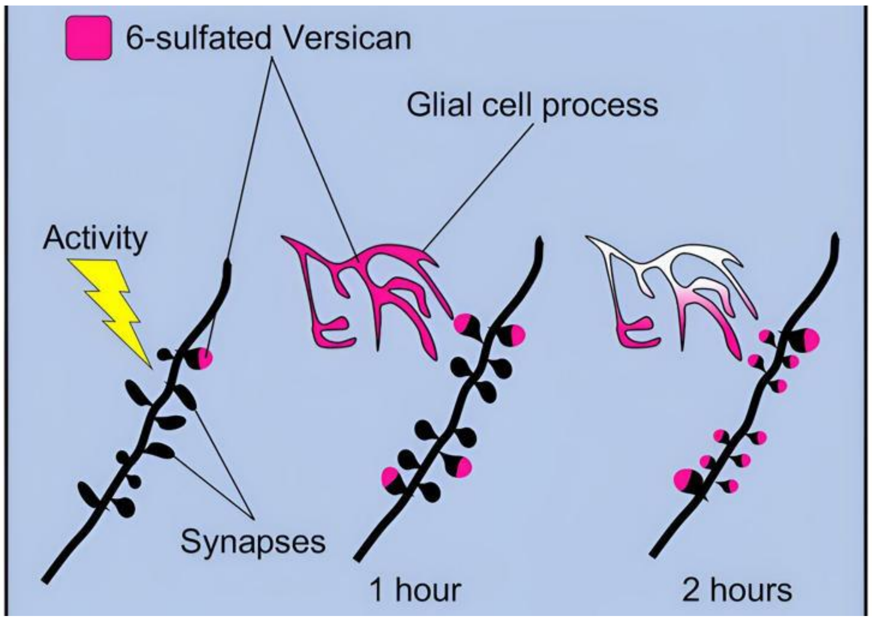
Researchers demonstrate a new mechanism of neural plasticity underlying learning and memory processes



Graphical abstract. Credit: Cell Reports (2024). DOI: 10.1016/j.celrep.2024.114112© Provided by Medical Xpress

Neurons are important, but they are not everything. Indeed, it is "cartilage," in the form of clusters of extracellular matrix molecules called chondroitin sulfates, located in the outside nerve cells, that plays a crucial role in the brain's ability to acquire and store information.

A study published in *Cell Reports* describes a new mechanism of brain plasticity, or how nerve connections change in response to external stimuli. The paper is titled "Focal clusters of peri-synaptic matrix contribute to activity-dependent plasticity and memory in mice."

The work stems from a collaboration between the Harvard Medical School, the University of Trento, and the German Center for Neurodegenerative Diseases (DZNE) in Magdeburg.

"Sensory skills and the ability to understand our surroundings depend on the activity of the brain, which enables us to perceive and process stimuli that come from the outside world. Through our brains we are able to acquire and store new information, and to remember information we have already acquired," say Yuri Bozzi and Gabriele Chelini.

"This fascinating phenomenon is made possible by the brain's ability to continuously change the structure and effectiveness of neuronal connections (synapses) in response to external stimuli. An ability that goes by the name of synaptic plasticity. Understanding how synaptic modifications occur and how they contribute to learning and memory is one of the great challenges in neuroscience."

Yuri Bozzi is a professor at the University of Trento and co-senior author. Gabriele Chelini is the first author of the study. Chelini worked on this project starting in 2017, as a postdoctoral fellow in a lab directed by Sabina Berretta (McLean Hospital and Harvard Medical School, Boston), and completed the scientific publication during his years as a postdoctoral fellow in Bozzi's lab at the University of Trento.

At the center of the research are chondroitin sulfates, molecules well known for their role in joints, which also play a crucial function in brain plasticity, being an integral part of the brain's extracellular matrix, as was originally discovered in 2001 by Dr. Alexander Dityatev's group.

In 2007, a Japanese study described the presence of clusters of chondroitin sulfates, circular in shape, scattered seemingly randomly in the brain. This work had slipped into oblivion, however, until Sabina Berretta's translational neuroscience laboratory brought these structures back to the attention of the scientific community, renaming them CS-6 clusters (from chondroitin sulfate-6, which identifies their precise molecular composition) and demonstrating how these structures were associated with glial cells and were severely reduced in the brains of people with psychotic disorders.

Then in 2017, Gabriele Chelini, newly hired in Berretta's lab, was tasked with revealing the function of these clusters.

"First we went to explore these structures in detail, visualizing them at very high resolution. We found that they are essentially clusters of synapses coated with CS-6 and organized in a clearly recognizable geometric shape. We then highlighted a new type of synaptic organization," the scholars recount.

"At this point, we had to use some 'experimental creativity'; with a combination of behavioral, molecular and refined morphological approaches, we realized that these connections encapsulated in CS-6 clusters change in response to electrical activity in the brain."

"Finally, through collaboration with Alexander Dityatev at DZNE Magdeburg, and the efforts of Hadi Mirzapourdelavar from his group, we attenuated the expression of CS-6 in the hippocampus (the region of the brain responsible for spatial learning), and demonstrated that the presence of CS-6 is necessary for synaptic plasticity and spatial memory," Bozzi and Chelini point out.

"This work paves the way for a new way of thinking about brain functioning. It is possible that all synapses formed on different neurons within CS-6 clusters have the ability to respond chorally to specific environmental stimuli, and are involved in a common function aimed at learning and memory processes," they note.

"They seem to represent a new substrate of information integration and association formation at the multicellular level," add Dityatev and Berretta.

The work is the result of a collaboration between several laboratories, including the translational neuroscience laboratory (Sabina Berretta; McLean Hospital—Harvard Medical School, Boston), the neurodevelopmental disorders research laboratory (Yuri Bozzi; CIMeC—Centro Interdipartimentale Mente/Cervello, University of Trento) and the Molecular Neuroplasticity laboratory (Alexander Dityatev; DZNE Magdeburg).

More information: Gabriele Chelini et al, Focal clusters of peri-synaptic matrix contribute to activity-dependent plasticity and memory in mice, *Cell Reports* (2024). DOI: 10.1016/j.celrep.2024.114112

Provided by University of Trento

Brain creates multiple copies of single memory for robust storage

Brain creates multiple copies of single memory for robust storage

Aiming to comprehend the dynamics of memory in brains, scientists conducted a new study on mouse models and examined how memories are stored and modified in the hippocampus.

The hippocampus is a tiny, complex structure of the brain that plays an important role in learning, memory, and emotions.

Researchers from the University of Basel in Basel, Switzerland, found that memories of specific experiences are stored in the brain as multiple parallel copies distributed across a minimum of three different clusters of neurons.

These clusters emerge at different stages during embryonic development. The copies vary in terms of their duration, modifiability, and susceptibility to deletion over time.

Dynamics of memory preserves in the brain

Scientists sought to learn the dynamics of the brain, which preserves and adapts memories, to understand how these processes contribute to learning from past experiences and decision-making in changing environments.

The research team showed that the activation and timing of specific memory copies can significantly impact how we recall, modify, and utilize our memories.

Flavio Donato from the University of Basel explained in an official statement that the brain faces impressive challenges concerning memory.

“On one hand, it must remember what happened in the past, to help us make sense of the world we live in. On the other, it needs to adapt to changes happening all around us, and so must our memories, to help us make appropriate choices for our future,” says Donato.

Understanding how past experiences impact decision-making could be vital because memories help living beings learn from the past and adapt to changing circumstances, thus influencing future decisions and behavior.

Scientists also note that until the discovery of multiple memory copies, the mechanism behind the brain regulating a memory’s dynamics remained a mystery.

Parallel copies of stored memories

Upon studying the hippocampus in mice, the team observed that parallel copies of stored memories in neuron clusters emerged at different phases during embryonic development.

These copies vary in their accessibility over time, with early-born neurons maintaining long-term memories that become accessible only after some time, while late-born neurons store memories that are strong initially but fade over time. Middle-stage neurons store more stable memories.

“How dynamically memories are stored in the brain is proof of the brain’s plasticity, which underpins its enormous memory capacity,” stated first author Vilde Kveim.

This flexibility in memory storage explains how our brain can adapt memories over time, helping us learn from new experiences while still holding on to important long-term memories.

A statement by the researchers emphasizes that persistence through dynamics is a delicate act to balance, one for which they might now have an entry point to fully understand.

This finding could potentially help scientists treat issues such as traumatic memories that might be too overwhelming or intense for an individual to manage.

It could also aid in recovering memories that have faded or seem lost, offering new ways to manage and improve mental health.

Researchers are now aiming to understand the driving force behind how memories are encoded and modified in the brain, potentially leading to ways to alleviate the impact of intrusive memories.

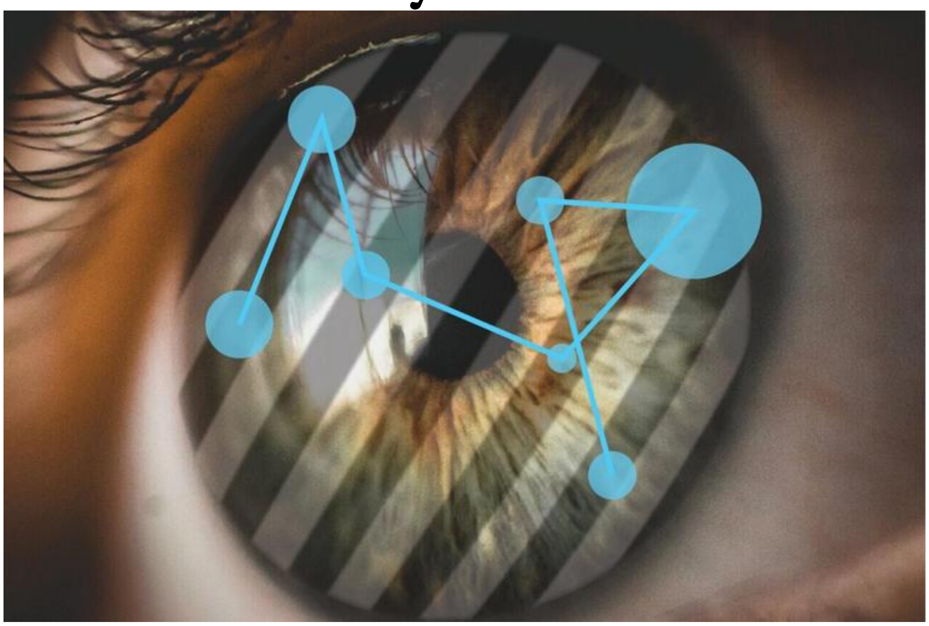
MindSpeech: Continuous Imagined Speech Decoding using High-Density fNIRS and Prompt Tuning for Advanced Human-AI Interaction

Suyi Zhang, Ekram Alam, Jack Baber, Francesca Bianco, Edward Turner, Maysam Chamanzar, Hamid Dehghani

In the coming decade, artificial intelligence systems will continue to improve and revolutionise every industry and facet of human life. Designing effective, seamless and symbiotic communication paradigms between humans and AI agents is increasingly important. This paper reports a novel method for human-AI interaction by developing a direct brain-AI interface. We discuss a novel AI model, called MindSpeech, which enables open-vocabulary, continuous decoding for imagined speech. This study focuses on enhancing human-AI communication by utilising high-density functional near-infrared spectroscopy (fNIRS) data to develop an AI model capable of decoding imagined speech non-invasively. We discuss a new word cloud paradigm for data collection, improving the quality and variety of imagined sentences generated by participants and covering a broad semantic space. Utilising a prompt tuning-based approach, we employed the Llama2 large language model (LLM) for text generation guided by brain signals. Our results show significant improvements in key metrics, such as BLEU-1 and BERT P scores, for three out of

four participants, demonstrating the method's effectiveness. Additionally, we demonstrate that combining data from multiple participants enhances the decoder performance, with statistically significant improvements in BERT scores for two participants. Furthermore, we demonstrated significantly above-chance decoding accuracy for imagined speech versus resting conditions and the identified activated brain regions during imagined speech tasks in our study are consistent with the previous studies on brain regions involved in speech encoding. This study underscores the feasibility of continuous imagined speech decoding. By integrating high-density fNIRS with advanced AI techniques, we highlight the potential for non-invasive, accurate communication systems with AI in the near future.

Neuroscientists reveal how brain coordinates attention and eye movements



Exploring the link between attention and eye movements. Credit: Priyanka Gupta/Pixabay© Provided by Medical Xpress

Two new studies from the Center for Neuroscience (CNS), Indian Institute of Science (IISc) explore how closely attention and eye movements are linked and reveal how the brain coordinates the two processes.

Attention is a unique phenomenon that allows us to focus on a specific object in our visual world, and ignore distractions. When we pay attention to an object, we tend to gaze towards it. Therefore, scientists have long suspected that attention is tightly coupled to rapid eye movements, called saccades. In fact, even before our eyes move towards an object, our attention focuses on it, allowing us to perceive it more clearly—a well-known phenomenon called pre-saccadic attention.

However, in a new study published in *PLOS Biology*, the researchers at CNS show that this perceptual advantage is lost when the object changes suddenly, a split second before our gaze falls upon it, making it harder for us to process what changed.

"Our study provides an interesting counterpoint to many previous studies which suggested that pre-saccadic attention is always beneficial," explains Devarajan Sridharan, Associate Professor at CNS and corresponding author of the study.

In the study, Priyanka Gupta, a Ph.D. student in Sridharan's lab, trained human volunteers to covertly monitor gratings (line patterns) presented on a screen, without directly looking at them, and to report when one tilted slightly. "Importantly, the participants did this task just before their eyes moved, in the pre-saccadic window. So, we were able to study the relationship between pre-saccadic attention and the detection of changes in the visual environment," explains Gupta.

A tracker was used to monitor their eye movements before, during and after their gaze fell on the object. "To our surprise, participants found it harder to detect the changes in the pre-saccadic window," Gupta adds.

In a follow-up experiment, they made the participants monitor two gratings presented one after the other quickly, again, just before their eyes moved. What the team found was that if the orientation of the second grating suddenly changed during this time, the participants tended to mix up the orientations of the two gratings—explaining the loss of the attentional advantage.

"This is essentially a basic science study," says Sridharan. But such insights, he adds, can be useful for how we track multiple objects in rapidly changing environments—in driving or flight simulators, for example.

In the other study, published in *Science Advances* and carried out with collaborators at Stanford University, the researchers devised an unusual experiment—this time, to decouple attention from eye movements—in monkeys.

Their goal was to tease out what is happening in the brain while these processes play out.

The monkeys had been trained on a counter-intuitive task called an "anti-saccade" task. Like the human study, the monkeys covertly monitored several gratings on a computer screen without directly looking at them. But when any one grating tilted slightly, the monkeys had to look away from it instead of focusing more sharply on it. This helped the researchers delink the location of the monkey's attention, from the location where its gaze ultimately fell.

Using a special kind of electrode called a "U-probe," they also recorded signals from hundreds of neurons across different layers of a specific region in the monkey's brain called the visual cortex area V4. What they found was that neurons in the more superficial layers of the cortex generated attention signals, while neurons in deeper layers produced eye movement signals.

Interestingly, these neurons also showed different activity patterns. "The superficial neurons increased their firing rates, to signal the object that needs to be attended to and prioritized for decision-making," says Adithya Narayan Chandrasekaran, first author of the *Science Advances* study and a former research assistant in Sridharan's lab at CNS. On the other hand, the deep neurons were tuning down their "noise," possibly to allow the animal to perceive the object better.

The researchers believe that uncovering such brain signatures can eventually point to what fails in attention disorders. Sridharan says, "Discovering such mechanisms is vital for developing therapies for disorders like ADHD."

More information: Priyanka Gupta et al, Presaccadic attention does not facilitate the detection of changes in the visual field, *PLOS Biology* (2024). DOI: 10.1371/journal.pbio.3002485

Adithya Narayan Chandrasekaran et al, Dissociable components of attention exhibit distinct neuronal signatures in primate visual cortex, *Science Advances* (2024). DOI: 10.1126/sciadv.adi0645

Provided by Indian Institute of Science

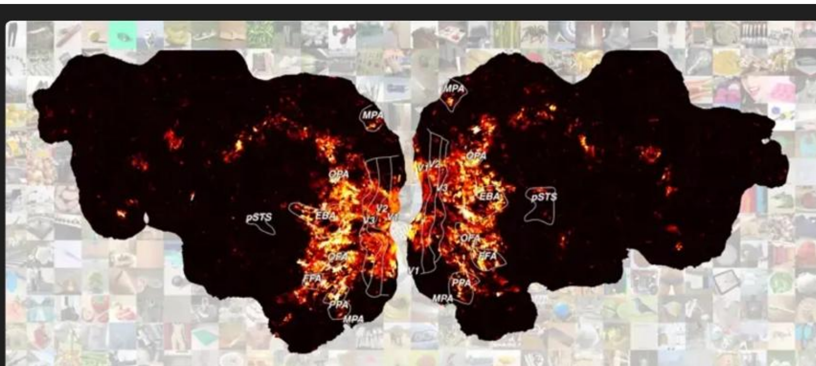
People think in many dimensions at the same time, study finds

Seeing the world around you may feel effortless. You open your eyes and can quickly distinguish people, animals, and objects in your surroundings.

Traditionally, scientists believed that the main goal of perception was to recognize and categorize these objects. However, new research suggests that the process might be more complex than previously thought.

A study led by the Max Planck Institute for Human Cognitive and Brain Sciences, the Justus Liebig University in Germany, and the National Institutes of Health in the USA indicates that brain activity during object recognition is influenced by various behaviorally important factors, not just categorization.

The traditional view of the brain's visual system suggested that when you see an object, your brain breaks it down into basic features—such as color, shape, and texture—and then reassembles these features to help you recognize and categorize it.



The brain activity of study participants was measured in the MRI scanner over 15 sessions while they saw over 8,000 different images of 720 objects. (CREDIT: MPI CBS)
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According to this view, the ultimate aim is to assign an object to a specific category, like recognizing that a dog is an animal. However, Martin Hebart, a group leader at the Max Planck Institute and professor at Justus Liebig University, explains that their findings challenge this idea.

He states, "Our results have shown that recognition and categorization are important goals of our vision, but by no means the only ones." Hebart adds that behaviorally relevant signals are found at all stages of visual processing, and these signals extend beyond mere recognition.

The researchers used a computational model to explore the way objects are represented in the brain. They identified 66 different dimensions based on behavioral data gathered from more than 12,000 participants.

These dimensions do more than just help categorize an object as, for example, a dog or an animal. They also explain various attributes like color, shape, and the typicality of an object—such as how typical a dog is as a representative of the animal category.

This broader set of dimensions allows a deeper understanding of how the brain perceives and makes sense of the environment. Hebart notes, "This allowed us to explain much better how our brain enables us to perceive the objects in our environment and understand their meaning."

The study examined the brain activity of three participants, who were shown over 8,000 different images of 720 objects while in an MRI scanner.

An fMRI encoding model of object dimensions underlying human similarity judgements. (CREDIT: MPI CBS)© The Brighter Side of News

First author Oliver Contier describes the results: "When the participants saw a rocket, for example, we were able to measure from the brain activity that their visual system not only recognized that it was a rocket or that a rocket is a vehicle, but also that it is grey and elongated, has to do with fire, can fly, or sparkles."

This demonstrates that the brain does not only recognize and categorize objects; instead, it processes a wide array of characteristics, engaging all perceptual processing stages.

This richer, multidimensional approach to understanding visual perception offers insights into how people make sense of what they see. Martin Hebart explains that their work reveals a "multidimensional framework that is consistent with the rich and diverse behavioral relevance of objects."

Regional tuning profiles across 66 object dimensions and representative images for selectivity of each region of interest in visual cortex. (CREDIT: MPI CBS)© The Brighter Side of News

Unlike a focus purely on categorization, this approach better captures the broad spectrum of human behavior and the complexity of interacting with the visual world. By considering multiple dimensions, the study shows how perception is not just about knowing "what" something is, but understanding a broader array of attributes that give it meaning in a variety of contexts.

Ultimately, this new perspective on vision can help explain human behavior more effectively than the traditional categorization-focused view. Whether recognizing an object, understanding its properties, or predicting how it might interact with its surroundings, the human visual system is far more dynamic than previously thought.

The findings underline the importance of behaviorally relevant features, which include not just the identity of objects but also qualities like form, function, and context.

Representational sparseness of behaviour-derived object dimensions in object-category-selective brain regions. (CREDIT: MPI CBS)© The Brighter Side of News

This approach provides a clearer understanding of how people navigate the visual complexities of everyday life. Instead of the brain working purely to sort objects into categories, each visual experience involves interpreting numerous dimensions simultaneously.

This insight offers a more complete picture of how perception works, shedding light on how individuals perceive, interpret, and respond to their environment.

How do you see pictures in your brain?

Why are some people able to visualize scenarios in their minds, with colors and details, and some people are not?

–Luiza, age 14, Goiânia, Brazil

Imagine you are in a soccer match, and it's tied. Each team will begin taking penalty kicks. The crowd is roaring, and whether or not your team wins the game depends on your ability to hit the shot. As you imagine this scene, are you able to picture the scenario with colors and details?

Scientists are hard at work trying to understand why some people can visualize these kinds of scenarios more easily than others can. Even the same person can be better or worse at picturing things in their mind at different times.

As neuroscientists in the fields of physical therapy and psychology, we think about the ways people use mental imagery. Here is what researchers do know so far.

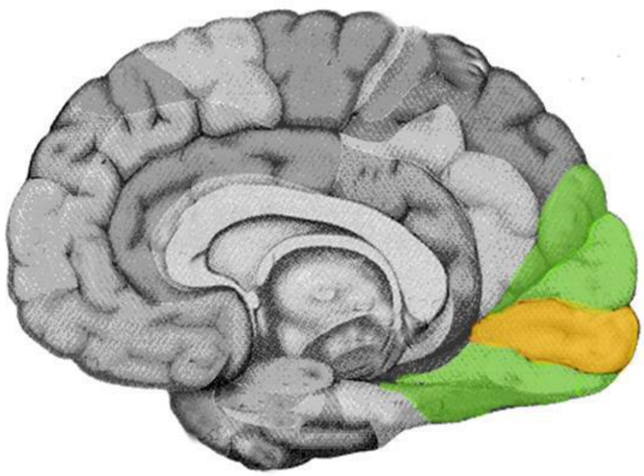
The brain and mental imagery

Mental imagery is the ability to visualize things and scenarios in your mind, without actual physical input.

For example, when you think about your best friends, you may automatically picture their faces in your head without actually seeing them in front of you. When you daydream about an upcoming vacation, you may see yourself on the sunny beach.

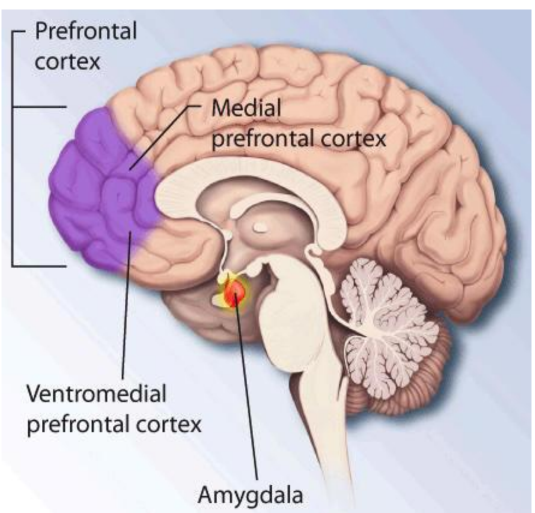
People who dream about taking a penalty kick could visualize themselves like they are watching a video of it in their mind. They may even experience the smell of the turf or hear the sounds that fans would make.

Related: Optical illusion reveals key brain rule that governs consciousness


The visual cortex influences both visual and mental imagery. (Image credit: Coxer via Wikimedia Commons)

Scientists believe your primary visual cortex, located in the back of your brain, is involved in internal visualization. This is the same part of the brain that processes visual information from the eyes and that lets you see the world around you.

Another brain region, located in the very front of the brain, also contributes to mental imagery. This structure, called the prefrontal cortex, is in charge of executive functions — a group of high-level mental skills that allow you to concentrate, plan, organize and reason.



The prefrontal cortex controls executive functions. (Image credit: The National Institute of Mental Health via Wikimedia Commons)

Scientists have found such skills to be, at least to some extent, related to one's mental imagery ability. If someone is good at holding and manipulating large amounts of information in mind, this person can play with things like numbers or images in their mind on the go.

Experiencing and remembering

Most of the same brain areas are active both while you're actually experiencing an event and also when you're visualizing it from a memory in your head. For example, when you behold the beauty of the Grand Canyon, your brain creates a memory of the image. But that memory is not simply stored in a single place in the brain. It's created when thousands of brain cells across different parts of the brain fire together. Later, when a sound, smell or image triggers the memory, this network of brain cells fires together again, and you may picture the Grand Canyon in your head as clearly as if it were in front of you.

Benefits of mental imagery

The ability to mentally visualize can be helpful.

Notice the look of concentration on a gymnast's face before competition. The athlete is likely visualizing themselves executing a perfect rings routine in their mind. This visualization activates the same brain regions as when they physically perform on the rings, building their confidence and priming their brain for better success.

Athletes can use visualization to help them acquire skills more quickly and with less wear and tear on their bodies. Engineers and mechanics can use visualization to help them fix or design things.

Mental visualization can also help people relearn how to move their bodies after a brain injury. However, with additional practice, those who do not use visualization will eventually catch up.

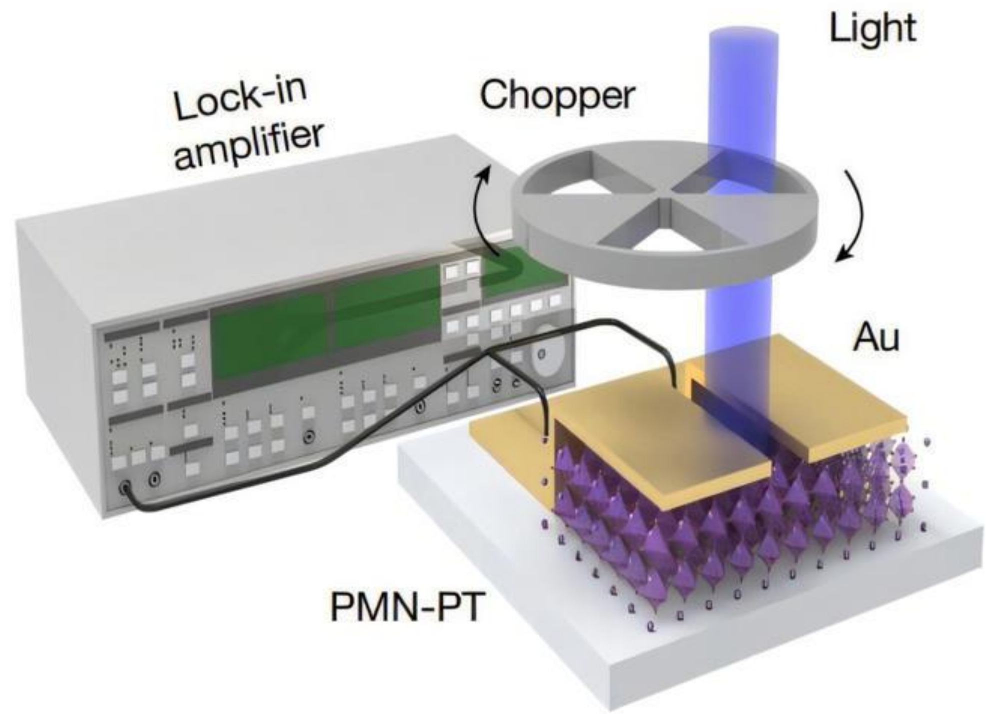
Nature-nurture interactions

All is not lost if you have difficulty visualizing. It is possible that the ability to visualize in your mind is a combined effect of both how your individual brain works and your life experiences.

For example, taxi drivers in London need to navigate very complicated streets and, scientists found, experience changes to their brain structures over the course of their careers. In particular, they develop larger hippocampuses, a brain structure related to memory. Scientists believe that the training the taxi drivers went through — having to visualize a map of complex streets across London in daily driving — made them better at mental imagery via changes in their hippocampus.

And watching someone else do a physical action activates the same brain areas as creating your own internal mental imagery. If you want to be able to do something, watching a video of someone else doing it can be just as helpful as visualizing yourself doing it in your head. So even if you struggle with mental visualization, there are still ways to reap its benefits.

New electronic 'skin' could enable lightweight night-vision glasses



Schematic showing the setup for characterizing a pyroelectric device fabricated based on ALO-enabled freestanding membranes. Credit: Nature (2025). DOI: 10.1038/s41586-025-08874-7. https://www.nature.com/articles/s41586-025-08874-7

MIT engineers have developed a technique to grow and peel ultrathin "skins" of electronic material. The method could pave the way for new classes of electronic devices, such as ultrathin wearable sensors, flexible transistors and computing elements, and highly sensitive and compact imaging devices.

As a demonstration, the team fabricated a thin membrane of pyroelectric material—a class of heat-sensing material that produces an electric current in response to changes in temperature. The thinner the pyroelectric material, the better it is at sensing subtle thermal variations.

With their new method, the team fabricated the thinnest pyroelectric membrane yet, measuring 10 nanometers thick, and demonstrated that the film is highly sensitive to heat and radiation across the far-infrared spectrum.

The newly developed film could enable lighter, more portable, and highly accurate far-infrared (IR) sensing devices, with potential applications for night-vision eyewear and autonomous driving in foggy conditions.

Current state-of-the-art far-IR sensors require bulky cooling elements. In contrast, the new pyroelectric thin film requires no cooling and is sensitive to much smaller changes in temperature. The researchers are exploring ways to incorporate the film into lighter, higher-precision night-vision glasses.

"This film considerably reduces weight and cost, making it lightweight, portable, and easier to integrate," said Xinyuan Zhang, a graduate student in MIT's Department of Materials Science and Engineering (DMSE). "For example, it could be directly worn on glasses."

The heat-sensing film could also have applications in environmental and biological sensing, as well as imaging of astrophysical phenomena that emit far-infrared radiation.

What's more, the new lift-off technique is generalizable beyond pyroelectric materials. The researchers plan to apply the method to make other ultrathin, high-performance semiconducting films.

Their results are reported in a paper appearing in the journal *Nature*. The study's MIT co-authors are first author Xinyuan Zhang, Sangho Lee, Min-Kyu Song, Haihui Lan, Jun Min Suh, Jung-El Ryu, Yanjie Shao, Xudong Zheng, Ne Myo Han, and Jeehwan Kim, associate professor of mechanical engineering and of materials science and engineering, along with researchers at the University Wisconsin at Madison led by Professor Chang-Beom Eom and authors from multiple other institutions.

Chemical peel

Kim's group at MIT is finding new ways to make smaller, thinner, and more flexible electronics. They envision that such ultrathin computing "skins" can be incorporated into everything from smart contact lenses and wearable sensing fabrics to stretchy solar cells and bendable displays.

To realize such devices, Kim and his colleagues have been experimenting with methods to grow, peel, and stack semiconducting elements, to fabricate ultrathin, multifunctional electronic thin-film membranes.

One method that Kim has pioneered is "remote epitaxy"—a technique where semiconducting materials are grown on a single-crystalline substrate, with an ultrathin layer of graphene in between. The substrate's crystal structure serves as a scaffold along which the new material can grow.

The graphene acts as a nonstick layer, similar to Teflon, making it easy for researchers to peel off the new film and transfer it onto flexible and stacked electronic devices. After peeling off the new film, the underlying substrate can be reused to make additional thin films.

Kim has applied remote epitaxy to fabricate thin films with various characteristics. In trying different combinations of semiconducting elements, the researchers happened to notice that a certain pyroelectric material, called PMN-PT, did not require an intermediate layer assist in order to separate from its substrate.

Just by growing PMN-PT directly on a single-crystalline substrate, the researchers could then remove the grown film, with no rips or tears to its delicate lattice.

"It worked surprisingly well," Zhang says. "We found the peeled film is atomically smooth."

Lattice lift-off

In their new study, the MIT and UW Madison researchers took a closer look at the process and discovered that the key to the material's easy-peel property was lead.

As part of its chemical structure, the team, along with colleagues at the Rensselaer Polytechnic Institute, discovered that the pyroelectric film contains an orderly arrangement of lead atoms that have a large "electron affinity," meaning that lead attracts electrons and prevents the charge carriers from traveling and connecting to another materials such as an underlying substrate. The lead acts as tiny nonstick units, allowing the material as a whole to peel away, perfectly intact.

The team ran with the realization and fabricated multiple ultrathin films of PMN-PT, each about 10 nanometers thin. They peeled off pyroelectric films and transferred them onto a small chip to form an array of 100 ultrathin heat-sensing pixels, each about 60 square microns (about .006 square centimeters). They exposed the films to ever-slighter changes in temperature and found the pixels were highly sensitive to small changes across the far-infrared spectrum.

The sensitivity of the pyroelectric array is comparable to that of state-of-the-art night-vision devices. These devices are currently based on photodetector materials, in which a change in temperature induces the material's electrons to jump in energy and briefly cross an energy "band gap," before settling back into their ground state.

This electron jump serves as an electrical signal of the temperature change. However, this signal can be affected by noise in the environment, and to prevent such effects, photodetectors have to also include cooling devices that bring the instruments down to liquid nitrogen temperatures.

Current night-vision goggles and scopes are heavy and bulky. With the group's new pyroelectric-based approach, NVDs could have the same sensitivity without the cooling weight.

The researchers also found that the films were sensitive beyond the range of current night-vision devices and could respond to wavelengths across the entire infrared spectrum.

This suggests that the films could be incorporated into small, lightweight, and portable devices for various applications that require different infrared regions. For instance, when integrated into autonomous vehicle platforms, the films could enable cars to "see" pedestrians and vehicles in complete darkness or in foggy and rainy conditions.

The film could also be used in gas sensors for real-time and on-site environmental monitoring, helping detect pollutants. In electronics, they could monitor heat changes in semiconductor chips to catch early signs of malfunctioning elements.

The team says the new lift-off method can be generalized to materials that may not themselves contain lead. In those cases, the researchers suspect that they can infuse Teflon-like lead atoms into the underlying substrate to induce a similar peel-off effect. For now, the team is actively working toward incorporating the pyroelectric films into a functional night-vision system.

"We envision that our ultrathin films could be made into high-performance night-vision goggles, considering its broad-spectrum infrared sensitivity at room-temperature, which allows for a lightweight design without a cooling system," Zhang says.

"To turn this into a night-vision system, a functional device array should be integrated with readout circuitry. Furthermore, testing in varied environmental conditions is essential for practical applications."

More information: Jeehwan Kim, Atomic lift-off of epitaxial membranes for cooling-free infrared detection, *Nature* (2025). DOI: 10.1038/s41586-025-08874-7. www.nature.com/articles/s41586-025-08874-7

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Provided by Massachusetts Institute of Technology

F35 Helmet: Gen III Mounted Display System (HMDS)

Introduction

In the high-stakes world of multi-role tactical aircraft piloting, split-second decision-making can quite literally be a matter of life or death. As technology continues to advance, the tools available to pilots have become increasingly sophisticated, none more so than th**e F-35 Gen III Helmet Mounted Display**

System (**HMDS**). This revolutionary interface offers pilots intuitive access to an extensive array of flight, tactical, and sensor information, ultimately enhancing situational awareness, precision, and safety to unprecedented levels.

A Glimpse into the Future

The F-35 Gen III HMDS serves as the pilot's primary display system, ushering in the next generation of cockpit interfaces. This innovative technology allows pilots to see through the bottom of the fuselage or directly at a target, providing an uninterrupted display of flight information and sensor data. The result is extreme spatial orientation, superior weapons targeting, and tactical superiority, whether it's day or night.

One of the standout features of this system is the seamless integration of the head-up display (HUD), helmet-mounted display, and visor-projected night vision. This integration empowers pilots with unparalleled capabilities inside the fighter cockpit. They can effectively target their weapons while maintaining advanced spatial awareness, all while continually monitoring crucial flight information.

The F-35 Gen III HMDS boasts an advanced bi-ocular display system with an expansive 30-by-40-degree field-of-view and a remarkable 100 per cent overlap. This feature becomes especially valuable during night missions, as the HMDS projects directly onto the visor, eliminating the need for separate night-vision goggles. Pilots can now seamlessly transition between day and night operations, further enhancing their flexibility and effectiveness.

Visual Targeting at Its Finest

One of the system's standout capabilities is the pilot's ability to target weapons simply by looking at and designating their intended targets. This innovative approach to targeting, combined with target verification through onboard sensors or datalink cues, streamlines the engagement process. It ensures that pilots can respond rapidly and accurately to threats, a critical factor in modern aerial combat.

Design and Comfort

Beyond its technical prowess, the F-35 Gen III HMDS also prioritizes the pilot's comfort and well-being. Its lightweight design maintains an optimal centre of gravity, enhancing overall manoeuvrability and reducing fatigue during extended missions. Additionally, the custom helmet liner ensures a precise fit, offering unmatched comfort that is essential for pilots operating under high-stress conditions.

Conclusion

In the ever-evolving landscape of aerial combat, the F-35 Gen III Helmet Mounted Display System stands as a testament to human ingenuity and innovation. It equips pilots with the tools they need to make split-second decisions, enhancing their situational awareness, precision, and safety to unprecedented levels. As we move forward into an era of advanced technology, this system serves as a beacon of hope for the brave men and women who protect our skies.

FAQs

How does the F-35 Gen III HMDS improve situational awareness?

The F-35 Gen III HMDS offers an uninterrupted display of flight information and sensor data, providing extreme spatial orientation, superior weapons targeting, and tactical superiority to pilots, day or night.

Can pilots switch between day and night operations seamlessly?

Yes, thanks to the advanced bi-ocular display system and visor-projected night vision, pilots can transition between day and night missions without the need for separate night-vision goggles.

How does visual targeting work with the HMDS?

Pilots can target weapons by simply looking at and designating their intended targets. Target verification is achieved through onboard sensors or datalink cues, ensuring accurate engagement.

Is the F-35 Gen III HMDS comfortable for pilots?

Yes, the system features a lightweight design with an optimal centre of gravity and a custom helmet liner for a precise fit, reducing pilot fatigue and increasing comfort.

What role does the F-35 Gen III HMDS play in modern aerial combat?

This system plays a crucial role by equipping pilots with the tools they need for split-second decision-making, enhancing situational awareness, precision, and safety in the ever-evolving landscape of aerial combat.

F-35 Gen III Helmet Mounted Display System (HMDS)

Unprecedented capability for the world's most advanced tactical aircraft

- Helmet Mounted Displays (HMD)/
- F-35 Gen III Helmet Mounted Display System

To the multi-role tactical aircraft pilot, split-second decision-making can be a matter of life or death. The F-35 Gen III Helmet Mounted Display System's next generation interface provides pilots with intuitive access to vast quantities of flight, tactical, and sensor information for advanced situational awareness, precision and safety.

Collins Aerospace CEVS JSF Helmet Mounted Display

Revolutionary Situational Awareness

The next-generation user interface serves as the pilot’s primary display system, and virtual capabilities enable them to see through the bottom of the fuselage or directly at a target. With an uninterrupted display of flight information and sensor data, the pilot experiences extreme spatial orientation, superior weapons targeting, and tactical superiority–both day and night.

Integrated HUD, display and night vision

The head-up display (HUD), helmet-mounted display, and visor-projected night vision are fully integrated to provide pilots with unprecedented capability in the fighter cockpit. They can target their weapons and maintain advanced spatial orientation while continually monitoring critical flight information.

Bi-ocular display system with full day and night vision

Advanced bi-ocular, 30-by-40-degree-wide field-of-view has 100 percent overlap. For night missions, the HMDS projects directly onto the visor, eliminating the need for separate night-vision goggles

Visual targeting

The HMDS enables the pilot to target weapons by looking at and designating targets, and target verification when receiving steering cues from onboard sensors or via datalink.

High performance design with optimal center of gravity

The lightweight design has an optimal center of gravity and Active Noise Reduction (ANR). The custom helmet liner ensures precise fit and comfort for reduced pilot fatigue.

THE MODERN BATTLESPACE
BROUGHT TO YOU BY COLLINS AEROSPACE

The F-35 Helmet – a Modern Marvel That Creates a Unique Maintenance Challenge

"We get pilots from a wide range of backgrounds, including fighter and helicopter pilots. Many of them have reported to us that this helmet system is the lightest, best-fitting and most stable they've ever experienced."

For the military pilot, the ability to perceive threats around their aircraft is the difference between life and death. To give military aviators immediate access and visualization of the data and intelligence they need to increase survivability and accomplish their missions, companies like Collins Aerospace have worked to display data in the most effective place for the pilot –in front of their eyes.

The personal-fit headgear display system utilized by the aviators flying America's next-generation F-35 joint strike fighter, offers unparalleled situational analysis, visual accuracy, and flight safety. To do so effectively, it needs to be custom-fit to the pilot, and any wear and tear that compromises that fit can have negative impacts on the wearer's ability to fly their mission.

The Modern Battlespace recently talked with Arthur De Ruiter and Dustin Vagedes of Collins Aerospace, about how the F-35 headgear outperforms helmets from the past. They also explained why wear and tear can be detrimental, and why maintaining these personalized fit helmets can be challenging.

The Modern Battlespace (TMB): *How are F-35 helmets and visors superior to prior models? What makes them unique?*

Arthur De Ruiter: The F-35 helmet and visor system is truly an engineering marvel that represents today's fifth-generation warfighter. The key difference between the F-35 helmet and a traditional fourth-generation warfighter helmet used on the F-16 is that all the flight and mission data is presented to the pilot on a display, mounted to the helmet.

"IF THE PILOT LOOKS AROUND IN CERTAIN CONDITIONS, THEY DON'T SEE THE COCKPIT OR EVEN THEIR LEGS… ALL THEY SEE ARE THEIR SURROUNDINGS LIKE TERRAIN" – ARTHUR DE RUITER

In addition, the helmet is connected to six infrared cameras located around the aircraft, providing a 360-degree view and unprecedented situational awareness. If the pilot looks around in certain conditions, they don't see the cockpit or even their legs. All they see are their surroundings like terrain, with the flight critical and mission data projected inside the helmet.

Dustin Vagedes: Indeed — the F-35 helmet is unlike any other in history. The Collins Aerospace F-35 Helmet Mounted Display System (HMDS) was designed to realize and exploit a true pilot-to-machine union.

"THE CONNECTION OF THE HMD TO THE AIRCRAFT IS UNIQUE FOR EACH PILOT… TO ACCOMMODATE TORSO LENGTH AND RANGE OF MOTION CHARACTERISTICS." – DUSTIN VAGADES

Weighing in at around five pounds, this system hosts an on-visor, bi-optical Heads-Up Display (HUD) to include digital night vision and imagery overlay from the aircraft's Distributed Aperture System (DAS), set to each pilot's interpupillary distance for optimal display quality. The connection of the HMD to the aircraft is unique for each pilot through different length interface cables to accommodate torso length and range of motion characteristics.

TMB: *Obviously, all equipment requires maintenance. How does wear-and-tear affect an F-35 pilot's helmet and visor? Does this headgear last a long time, or will it eventually deteriorate after a few years?*

Arthur De Ruiter: Inside the helmet shell are custom-milled pads that generally experience normal wear and tear. Other than being exposed to sweat or hair grease, they usually last a long time if the helmet is well fitted. Visors typically get scratched by frequent handling and need to be replaced more often. That can be a challenge because they must be custom-trimmed to fit the oxygen mask.

"ANYTHING THAT CREATES MINIMAL SPACE BETWEEN THE CRANIUM AND THE CUSTOM MILLED PADS CAN CREATE A PROBLEM OVER TIME, POTENTIALLY REQUIRING A HELMET REFIT AND UPDATED OPTICAL CALIBRATION." – ARTHUR DE RUITER

The need for helmet refitting becomes really important when physical changes are happening with the pilot, such as weight or hairstyle changes. Anything that creates minimal space between the cranium and the custom milled pads can create a problem over time, potentially requiring a helmet refit and updated optical calibration.

Over time, the pilot will notice if there are any issues by feeling uncomfortable "hot spots" or even double vision, which can lead to fatigue, headaches, and long-term neck injuries. It is important that pilots immediately report any of these issues to their life safety equipment teams, so they can contact Collins Aerospace to solve any fit issues.

Dustin Vagedes: These helmets have proven to be quite resilient. The F-35 has now logged over 400,000 flight hours to date and our 2,000-plus HMDs custom fit and delivered to date have held up well. The HMD system was designed to be operated and maintained in the most austere conditions our warfighters may be operating within. With this in mind, the HMD was designed with seven-line replaceable units (LRUs), that can be serviced or replaced in the field as necessary.

"THE HELMETS GO THROUGH A LOT DURING THEIR LIFETIME [WHICH WAS] CONSIDERED DURING THE DESIGN OF THE HELMET… TO REDUCE THE NEED FOR RETURNS TO THE FACTORY FOR MAJOR REPAIRS" – DUSTIN VAGEDES

The helmets go through a lot during their lifetime. Between missions, they are stuffed in the pilots' helmet bags and stored in their flight lockers. Helmet maintenance and cleaning are often performed by schedule-saturated technicians, who may be stressed with meeting their assigned time-sensitive missions. Pilots can even bang the helmets against things in the cockpit while doing aggressive head turns while checking their "six". All these things were considered during the design of the helmet and factor into continuous design improvements to reduce the need for returns to the factory for major repairs — saving our customers and our end users money in the long run.

The helmets hold up quite well over time. It's the visors that are most likely to need replacement since they're supposed to be clean and clear but are exposed during use and storage. Any scratches on the surface of a visor might become an annoyance to a pilot even if they don't affect helmet functionality.

TMB: *What has the process traditionally involved for replacing a pilot's helmet and visor? Can they just use replacement parts, or is there a process that must be followed?*

Dustin Vagedes: The previous helmet-mounted display systems have typically been built around a fairly universal helmet shell and require extensive modifications to replace and/or reconfigure for their specified use and reuse.

The Collins Aerospace F-35 HMD's consistent configuration and integrated design provide a repeatable fit as replacement parts are installed.

The custom-milled liner and visor files are retained indefinitely and are provided to the end-user to further ensure continuity of the performance and fit. These replacements are typically provided by the services-life-support personnel who follow the OEM maintenance process to return a helmet to service, after being trained or re-trained by Collins Aerospace.

Arthur De Ruiter: In the current fitting process, pilot cadets will get their new helmet fit at a Pilot Fit Facility, typically at a US Air Force Base like Luke. This is a two-day process and after they have been fitted, they go straight into their extensive training program. Unless there is a major problem with the helmet seen during training flights, we typically do not see the pilot again.

"IF ANYTHING HAPPENS TO THE HELMET… THEY WOULD NEED TO GO THROUGH THE ENTIRE FITTING PROCEDURE AGAIN, WHICH MEANS RETURNING TO AT PILOT FIT FACILITY IN THE US." – ARTHUR DE RUITER

Once they become deployed at their home base and fly extensive hours, they are on their own to work with the services-life-support teams. If anything happens to the helmet that affects the perfect fit beyond what can be resolved with a simple replacement part, they would need to go through the entire fitting procedure again, which means returning to at Pilot Fit Facility in the US. Fortunately, Collins Aerospace has developed a technology that will get pilots back in the air sooner, by bringing the solution to the customer.

Designed to work with the F-35 Lightning II, the custom-fitted helmet serves to increase pilot responsiveness through enhanced situational awareness. Real-time imagery from the aircraft's six exterior cameras is streamed onto the helmet's display providing the pilot a view that would otherwise be obscured. (U.S. Air Force photo by Senior Airman Erica Webster)

An inside look at F-35 pilot helmet fittings

- Published Aug. 5, 2021
- By Senior Airman Erica Webster
- 419th Fighter Wing Public Affairs

HILL AIR FORCE BASE, Utah (AFNS) --

Reservists in the 419th Operations Support Squadron play a crucial role to ensure the safety of pilots assigned to the **419th Fighter Wing**, the **Air Force Reserve**'s only combat-capable **F-35 Lightning II** unit.

"We are responsible for maintaining and repairing pilot gear to ensure everything is in proper working condition," said Staff Sgt. AJ Arteaga, 419th OSS aircrew flight equipment Reservist. "That also includes their helmet."

Every helmet is custom-fitted to its pilot during a two-day process at a fit facility. To begin assembly of the helmet, pilots have their heads measured and scanned to secure the perfect fit.

Tech. Sgt. Anthony Farnsworth, 419th Operations Support Squadron, adjusts an F-35 Lightning II helmet during optical fit training at Hill Air Force Base, Utah, July 10, 2021. Each helmet is inspected every 105 days and has a 120-day fit check to ensure its functionality and safety. (U.S. Air Force photo by Senior Airman Erica Webster)

Staff Sgt. AJ Arteaga, 419th Operations Support Squadron, adjusts the head position of Tech. Sgt. Anthony Farnsworth, 419th OSS, during F-35 Lightning II helmet optical fit training at Hill Air Force Base, Utah, July 10, 2021. Reservists in the 419th OSS are responsible for maintaining and repairing pilot gear to ensure it is in proper working condition. (U.S. Air Force photo by Senior Airman Erica Webster)


Tech. Sgt. Anthony Farnsworth, 419th Operations Support Squadron, demonstrates the F-35 Generation III Helmet-Mounted Display at Hill Air Force Base, Utah, July 10, 2021. The display provides the pilot critical information, built-in night vision, and allows a 360-degree view of the aircraft's outside environment. (U.S. Air Force photo by Senior Airman Erica Webster)

Once assembled, pilots need to have the optics aligned using a pupilometer, which measures the distance between their pupils within two millimeters of its center, so pilots see a single image on the helmet-mounted display.

On the display, pilots are able to view mission-critical information and obtain enhanced situational awareness of the battlefield simply by moving their head. The helmet gives pilots a 360-degree view of the F-35's external environment without needing to tip the jet.

"The pilot can look down through a portion of their wing and see what's below," said Tech. Sgt. William Vass, 419th OSS. "When they look toward the cameras embedded on the F-35 that image projects onto their helmet display."

The helmet's innovative technology and precise fit require routine maintenance so pilots can complete their mission. In addition to pre- and post-flight fittings, the helmet is inspected every 105 days and has a 120-day fit check to ensure its functionality and safety.

"Pilots come in and put on all their gear so we can double-check to make sure everything fits properly and without issue," Arteaga said. "Small things such as a new haircut or a couple of pounds gained could cause the helmet to not fit correctly."

Mask adjustments are also included within the helmet fitting. Pilots are sent to an oxygen tester where aircrew flight equipment technicians can identify any leaks around the mask that could prevent adequate oxygen flow.

"The pilot can look down through a portion of their wing and see what's below. When they look toward the cameras embedded on the F-35 that image projects onto their helmet display."*Tech. Sgt. William Vass*

"The next part is to ensure there is a proper distance between the mask and the visor," Arteaga said. "We have to make sure when the pilot moves or talks, the mask doesn't hit the visor. If it's too close, it will bend the visor and distort the display image."

Reservists in the AFE shop are an integral part of the helmet-fitting process and maintenance intervals. They verify it remains as precise as possible to guarantee the safety of the 27 pilots in the 419th FW. The work is involved and in-depth, but essential to providing a seamless interaction between the helmets' advanced capabilities and the exacting skills of the pilot wearing it.

F-35 HELMET, AHEAD OF OUR TIME

When the DoD launched the acquisition process for the revolutionary multi-service, multi-role, single seat, single engine strike fighter aircraft known as the F-35 Lightning II, they envisioned a common platform across three variants that ultimately invigorated the defense industry world-wide, creating an influx of new technologies — notably the F-35 helmet.

A vital element of the F-35's unprecedented warfighter capability, the helmet's ground-breaking technology equips the pilot with mission-critical information on the helmet's visor; resolves well-documented fit, comfort, and convenience problems associated with helmets worn by pilots of legacy aircraft; and fuses together the F-35's cutting edge communications and sensor suite to form a clear picture of the operating environment —

giving F-35 pilots unrivaled situational awareness and a decisive advantage over adversaries.

The latest iteration — known as the Generation III helmet — is also easily realigned and readjusted based on the individual pilot's needs, whereas previous legacy F/A-18 helmets are rigid, cumbersome, and require manual upgrades.

While onboard the amphibious assault ship USS America (LHA 6) during the third and final shipboard phase of F-35B Lightning II developmental test (DT-III), Marine Corps Sgt. Nicholas Voegeli and Desirée Smith, F-35 Lightning II Pilot Systems Integration-Human Systems engineer, demonstrated the advancements featured in the F-35's Gen III helmet.

Fabricated with its own Display Management Computer Hardware operating system the helmet enables pilots to toggle through different modes of data visualization. It also delivers a more efficient video feed than the F-35's Gen II helmets — equipping pilots with symbology correlated inside the cockpit as well as outside the aircraft with the use of the Distributed Aperture System (DAS). Using multiple DAS cameras installed peripherally around the aircraft, the pilot is able to display various modes of imagery such as thermal, night vision, and actual and achieve an unprecedented look-through-aircraft capability. All modes are beneficial to pilots as they deliver a clear 360-degree picture during daylight and lowlight settings. Thermal images portrayed through DAS enable pilots to view heat signatures emitted by various objects. For instance, a pilot can identify a ship running a hot engine against the vast darkness of the cold ocean. Night vision can also assist in magnifying low visibility objects against areas of very little to no light.

"The helmet mounted display (HMD) allows critical flight data to be viewable anywhere I look," added Marine Corps Major John "IKE" Dirk, a test pilot and the F-35B DT-III Officer-In-Charge (OIC) from the Pax River Integrated Test Force (ITF) assigned to Air Test & Evaluation Squadron (VX) 23 based at Naval Air Station Patuxent River, Maryland.

"In addition to the aircraft's flight symbology, I can display tactical data and even live night vision video. The helmet helps me find friendly and enemy aircraft, locate targets on the ground, and can even point out the ship. It is fully integrated into the aircraft systems and enables a seamless transition between tactical display and the outside world," he added.

Joint Helmet Mounted Cuing System (JHMCS) helmets worn by pilots of legacy jets such as F/A-18 Hornets, Super Hornets, and AV-8B Harriers, take a long time to install equipment enhancements while F-35 Gen III helmets are specially designed to facilitate the quick installation of equipment, thereby reducing the maintenance time required for each helmet.

Another problem with JHMCS legacy helmets is the graphics on the display visor, which block the pilot's ability to see through an overly bright image. Engineers worked to refine this imagery on previous iterations of the Gen III helmet and now the latest helmet enables pilots to toggle through several gradients of opacity. The pilot is also able to devote less time switching through different modes and doesn't have to physically install Night Vision Goggles before starting a night mission because the Night Vision Device (NVD) is built-in.

"Legacy systems are often limited to a fixed heads-up display or separated into several systems — targeting helmet, night vision goggles, heads up display, etc.," Dirk said. "The F-35 helmet integrates all of these capabilities and more into one balanced and comfortable helmet, complete with active noise reduction."

These technological advancements of the F-35 Gen III helmet will save military expenditures due to several new factors.

The use of laser scanning technology creates an exact replica of a pilot's skull, thereby fabricating a portable styrofoam helmet liner that is a break-through above and beyond the traditional custom-designed helmet for each pilot. This styrofoam cap fits into any size helmet, enabling a pilot to take the helmet liner from squadron to squadron for use throughout his or her career, optimizing the flexibility of the pilot flight equipment inventory, eliminating risk of damage to helmets during squadron transitions, and reducing investments in large inventories of helmets.

As the pilot dons the cap and helmet, two ocular cameras situated above the helmet’s display visor are manually aligned to his or her interpupillary distance (IPD) settings for each eye to ensure the acuity of each pilot’s vision and establish the proper fit of each helmet.

“The helmet is definitely well worth it considering what it brings to the fleet, the capability it brings to the warfighter who keeps us safe, and how it equips all of the pilots,” said Smith, referring to the clear 360-degree picture of the battlespace that the helmet delivers.

This unrivaled situational awareness equips the pilot with an unparalleled ability to dominate the tactical environment. Likewise, commanders at sea, in the air or on the ground immediately receive information collected by the F-35’s sensors via data link — empowering them with an instantaneous, high-fidelity view of ongoing operations, making the F-35 a formidable force multiplier while enhancing coalition operations.

Additionally, legacy aircraft only displayed targets on screens installed inside the actual cockpit, creating a disadvantage because pilots would have to turn their heads away from their surroundings. Now, F-35 pilots can focus on their targets via the Gen III helmet display visor. This empowers them to keep track of adversaries farther than they could ever turn their heads.

"You can't put a price on the blanket of freedom that this aircraft will deliver,” Voegeli added. “The threat of any adversary who wishes to bring us harm is ultimately the reason to test this next generation fighter jet. The moment this aircraft is put in the fight all questions will come to an end."

The quantity of specifications in this piece of revolutionary equipment showcases the DoD’s integration of pilot equipment with its next generation strike fighter, its focus on warfighter performance and pilot safety, and its ability to inspire technological advancements that ensure U.S. air combat superiority for generations to come.

How The Brain Decides Which Memories To Keep And Which To Discard

We've known for some time now that during sleep, the brain undergoes a memory spring cleaning of sorts, during which thoughts collected during that day are either converted into long-term memories or discarded.
It makes sense that this brain cleanse would occur at night when the brain is idle, considering there's no way that even the enormous human brain could possibly have enough room for everything that we take in on a given day.

Until recently, researchers didn't understand the mechanism for how the brain chooses what to keep. But, in a study recently published in the journal *Science*, researchers have demonstrated for the first time that during the day the brain goes through a series of steps in an effort to tag certain memories to be stored that night.

How the Brain Stores Memories

Researchers found that when the brain is idle during the day, simultaneous waves of neurons come together in what's called sharp wave ripples that literally shout to the rest of the brain that this memory is important and needs to be tagged for storage later that evening.

While sharp wave ripples happen less often during the day, their role is crucial because at night a series of 2,000-4,000 sharp wave ripples occur, causing the brain to condense its collection of memories.

"Sharp wave ripples are a pattern that occurs in the hippocampus, and in the wake state, this is the pattern that selects what will be put in for permanent storage and what will be triaged," says lead study author György Buzsáki, the Biggs Professor of Neuroscience at the New York University School of Medicine.

These sharp wave ripples make up the "most synchronous pattern in the mammalian brain," and they occur when the brain is offline, either idling during the day or at night.

"It takes what's good about sharp wave ripples in the brain to the next level," says Jim Gnadt, co-lead of the Integrative and Quantitative Neuroscience Team for the NIH BRAIN Initiative, who was not involved in the study.

How Rest Impacts Memory Storage

It seems that the brain cuts up the experiences that happen druing our day and combines them with other experiences that also occurred. Parts are removed, and thoughts are condensed.

"Many parts of our waking experience are cut out and bound together with other experiences using this pattern in the hippocampus," says Buzsáki.

As part of the study, researchers allowed rodents to run through a maze many times and looked at their brains while they were doing it. They found that when the mice were at rest drinking sugar water, that was when the sharp wave ripples occurred. The longer the rodents stayed by the water cooler, the more sharp waves that occurred in the brain. After the animal went to sleep and there were multiple sharp waves over night, the maze run that was replayed the next day was the one that occurred just before their water cooler idle rest.

The Brain's Two Algorithms

It turns out that the brain has two modes or algorithms: an acquisition mode and a storage mode. It's not that the brain is at rest when we sleep, it's that it's storing what was tagged during the day. "Sharp wave ripples happen when we're not attentive, but they are as important as the active state," says Buzsáki.

That's part of the reason that breaks are so important to the brain functioning at a higher level. Going for a run or taking a coffee break is the best way to remember or learn something complicated. You have to be at rest in creative work in order to have the best results.

Gnadt says that this research takes the whole idea of how memory works to the next level. "It gives us a better idea of why during sleep the brain grabs onto certain memories and not others," he says. Our brains are constantly doing the work of collecting and storing and this is another tool in understanding the mechanism for how it all comes together.

What happens in our brains when we 'hear' our own thoughts?

If you've ever had an imaginary argument in your head, you may have "heard" two voices at once. Your own inner voice and that of the other person in the quarrel. You may even "hear" the other person's accent, or the timbre of their voice.

So what's happening in the brain when that inner monologue is running? How is it that you can "hear" your thoughts?
As it turns out, the brain undergoes similar processes when you're thinking words as when you're speaking out loud.

Inner monologues are thought to be a simulation of overt speech, said Hélène Loevenbruck, a senior neurolinguistics researcher and head of the language team in the Psychology and NeuroCognition Laboratory at CNRS, the national French research institute. When we're children, we're virtual sponges, soaking up new information from every angle. Children playing alone will often speak dialogue aloud, for instance between a toy truck and a stuffed animal. At around 5 to 7 years old, that verbalization moves inward, Loevenbruck said.
Related: Does everyone have an inner monologue?
Earlier studies have shown that the brain exhibits similar activity with inner speech as it does with verbalized speech. When study participants are asked to deliberately "speak" inside their heads while lying in a magnetic resonance imaging (MRI) machine, scientists can see parts of the brain that process auditory information activate as if the participant were actually hearing the words.
"Cerebral regions activated during inner speech are quite similar to those that are activated during overt speech during real speech," Loevenbruck told Live Science. Those regions include the left hemisphere frontal lobe and parietal lobe, which help in processing outward stimulation.

But when you're thinking of something like a fictional argument with another person, the brain goes one step further. During that inner argument, you're playing two roles: yourself, and the person you're arguing with. When you play yourself, the auditory centers on the left side of your brain activate, Loevenbruck said. But when you internally switch roles to play the person you're arguing with, "there's a sort of a shift of cerebral region activation to the right hemisphere," in the equivalent areas like the parietal lobe and frontal lobe, she continued. Seeing the situation from a different perspective, even if it's a perspective you're crafting in your head, shifts which brain regions are engaged.

Researchers have also observed this phenomenon when participants are asked to imagine movement, Leovenbruck continued. Dancers, for instance, use a different part of their brain to imagine themselves dancing versus someone else dancing, a study published in the August 2005 issue of the journal Cerebral Cortex found.
It's one thing to see those brain regions activate when a person is told to think something, but it's much less understood what happens in our brains when we let our minds wander, Leovenbruck said. Not all inner monologues are deliberate. Sometimes words or sentences just pop into your head, unprovoked.

This phenomenon might have something to do with the brain's "default mode network," (DMN) said Robert Chavez, a neuroscientist at the University of Oregon. The DMN is a network of areas in the brain that are active when it is not engaged in a specific task. The DMN is thought to be involved with aspects of internal thought, such as retrieving memories, imagining the future, or interoception — a sense or "feeling" of what's happening in your body, such as hunger or thirst.

"The default mode network seems to be more active when your mind is wandering," Chavez told Live Science. Because the default mode network involves planning for the future by pulling from memories, recent experiences, and mental associations, it's thought that this combination of activities gives rise to an internal monologue while you focus inward.
A lot more research is needed to understand how inner thoughts arise spontaneously, Leovenbruck said. When taken to an extreme, inner thoughts can become dysfunctional, such as rumination after an uncomfortable or traumatic event, or in mental disorders, such as schizophrenia, in which people hear auditory hallucinations.

CAN WE EVER STOP THINKING

We often find ourselves in an endless thought loop. And every so often, we try to stop this endless flow of thoughts by telling ourselves to just stop thinking. But do we or can we ever really stop thinking?

It depends on how you define "thinking," said Michael Halassa, an assistant professor in the department of brain and cognitive sciences at MIT. A thought, which is the result of chemical firing between brain cells, can happen both on the conscious and unconscious level, he said.

The type of thinking we are aware of, such as the endless thoughts that pop up when we're trying to sleep, can, in theory, be silenced. That's presumably what meditation is all about, Halassa said.
But even though that's what meditators strive to do — it's not clear how much of a blank state they can actually achieve. "I don't know if [completely stopping thinking] is theoretically possible and if it is, I think that would be incredibly difficult to test," said Julia Kam, a cognitive scientist at the Knight Lab at the University of California, Berkeley.

But it's clear that "meditators are a lot more tuned into what their thoughts are," Kam told Live Science. "So when they're supposed to be focused on something and their mind shifts away, then they're just a lot better at picking up on that shifting of attention."

There's a difference between having a thought, and being aware that you're having a thought, she said. So if you ask someone what they're thinking about and they respond with "nothing," they could just not be aware that they're having thoughts, Kam said. For instance, you could be deeply in thought about a relationship or an upcoming test, and you only become aware of it when someone taps you on the shoulder and snaps you out of it, she said. People who are thinking about "nothing" could also be having stream of consciousness thoughts that don't tell a coherent story, Halassa said.

But the brain never actually stops "thinking" in a broader sense. Most thoughts are actually happening in the background without us being aware of them, and "there's not really a way to turn these things off," Halassa told Live Science.

If you see a familiar face in a crowd and think you know them, you might not be able to come up with how you know them right away, Halassa said. But maybe hours later, you'll suddenly remember. That's a result of your brain "thinking," in the background, he said.

Even making decisions happens mostly unconsciously. For example, some of this background "thinking" results in what we call a "gut feeling," Halassa said. "A lot of times our brains are crunching a lot of numbers and spitting out a gut feeling that we ultimately go with." We don't always have conscious access to our brain's decision-making process and sometimes we create a story to explain the decision — sometimes it's accurate, sometimes it's not, he added.

Kam agrees that how you define "thinking," changes the answer to the question. "If you mean thinking, as in having an inner dialogue with ourselves, then, yes, we can stop having that inner dialogue," Kam said. But if thinking means not focusing attention on anything in particular, "I think that would be a lot more difficult for the layperson."

Even sitting here reading this, thinking about thinking is sending messages across a chain of neurons in the brain. So if we somehow manage to stop ourselves from "thinking" consciously, or achieve a "blank state of mind" through meditation, the brain won't sign off. It will continue to have thoughts — we just won't be aware of them.

Why Do Our Brains Have Folds?

Most of us have long accepted that our brains look like overgrown, shriveled walnuts. But why do our brains have those telltale wrinkles?

The cortex, or the outer surface of the brain — what's colloquially referred to as "gray matter" — expands and subsequently folds as our brains develop in the womb, said Lisa Ronan, a research fellow in the Department of Psychiatry at the University of Cambridge in England.

In essence, this expansion causes pressure to increase in that outer surface, which is then mitigated by folding, Ronan, told Live Science. [What If Humans Were Twice as Intelligent?]

Basically, imagine pushing at either end of a piece of rubber — at some point, the surface will bend in response to the increasing pressure. Or, if you're into geology, think of it like two tectonic plates crashing into each other: The pressure during the collision eventually becomes so great that those plates experience a geological fold.

These countless folds allow humans to pack in more neurons which, in turn, can mean more advanced brains with increased cognitive abilities, Ronan said.

However, folded brains are hardly ubiquitous, as most animals' brains aren't folded. For instance, the cortex of mice and rats does not expand enough during development to lead to folding, meaning their brains are wholly smooth surfaces.

When brain folding does happen, it tends to occur in animals with larger brains, Ronan told Live Science in an email. "But this isn't always the case — some large mammals like the manatee have far fewer folds than researchers would otherwise expect based on the size of their brain," she said.

There's a good reason for this: whether a fold forms depends not only on the overall growth of the cortex, but also the physical properties of that part of the cortex. For example, thinner regions tend to fold more easily than others, Ronan said.

"You're born with a folded brain," said Ronan. "But a key and intriguing point of gyrification [the study of cortical folding] is that the brain folds in specific patterns."

Though the brains' ridges and valleys — called gyri and sulci, respectively — look random, they're actually consistent across individuals, and even some species. Ronan said this consistency is important because it indicates that the folding has meaning.

Ultimately, the physical properties and unique folding patterns of each cortex region are linked to its function.

"Having the largest surface area in and of itself isn't enough; it's also about cortex function," Ronan said. "Elephants have way larger, and more folded, brains than humans do. But obviously, we're at the top of the evolutionary tree, and they're not."
In other words, the function of our cortex is more advanced, at least in some respects, than the function of the elephant cortex, even though the elephant's brain has more wrinkles.

So, those wrinkles that make our brains look like raisins are ultimately useful; they help us pack a bigger cerebral punch in the same amount of skull space.

Want Better Mental Focus? Neuroscience Just Explained How to Train Your Brain to Achieve 'Flow State'

You might call it 'flow state' or 'being in the zone.' Would you be interested to learn how to make it happen?
This is a story about creativity, productivity, and neuroscience.

In 1990, a psychologist named Mihaly Csikszentmihalyi published a book in which he described "flow," a state of mind in which people can focus their brains, shut out distractions, and become much more productive.

Maybe you think of this as being "in the zone." People have spent entire careers trying to explain, analyze, and ultimately teach others how to enter into this kind of flow state.

Now, researchers out of Drexel University in Philadelphia say they've succeeded in using neuroimaging technology to track flow state in people's brains in real time -- and maybe unlock some practical advice on how to make it happen.

Writing in the journal *Neuropsychologia*, the researchers said they set out to consider two theories of how flow state might work:

- Theory 1 suggests that flow state might simply be, "a state of highly focused concentration or hyperfocus that shuts out extraneous thoughts and other distractions to enable superior performance on a task."

- Theory 2, however, suggests something a bit more active: The idea that through years of intense practice, people's brains can develop "a specialized network or circuit to automatically produce a specific type of ideas... with little conscious effort."

If the second theory were correct, the researchers hypothesized, this might mean that the brains of people who develop a certain level of expertise in a creative discipline might be able to "rela[x] its supervision" and basically go on autopilot -- flow state, almost on demand -- exploring and creating without active control.

"Csikszentmihalyi... defined [flow] as 'a state in which people are so involved in an activity that nothing else seems to matter,' " said lead researcher John Kounios. "'[T]he experience is so enjoyable that people will continue to do it even at great cost, for the sheer sake of doing it.'"

The Drexel experiment involved recruiting a group of 32 jazz guitarists, some of whom were highly experienced and others who were less so, and recording high-density electroencephalograms (EEGs) while they each improvised six jazz sessions, "with programmed drums, bass, and piano accompaniment."

Afterward, their performances were assessed both by (a) asking the guitarists to rate how intensely they felt they achieved a "flow state" while playing, and (b) asking four jazz experts to listen individually to each of the 192 total recorded improv sessions, and rate them for creativity and other qualities.

In the end, they made two very interesting findings:

- First, the more experienced musicians reached a flow state "more often and more intensely" than their less experienced colleagues -- thus suggesting support for "Theory 2," above.
- Second, they found that the EEGs mapping the brain activity of musicians who managed to achieve a high state of flow had two marked differences from other occasions: *increased* brain activity in the left hemisphere, in areas associated with "hearing and playing music," and *decreased* activity in the *superior frontal gyri*, which is associated with executive control.

What I really like about this effort is that Kounios was willing to make a few recommendations for creative people in any field who might want to increase the odds of attaining flow state.

In short, he said it involves building deep expertise in whatever creative discipline you care for, and then also practicing and also learning how to "withdraw conscious control" once you've reached that high level of expertise.

As I write in my free e-book, *Neuroscience: 13 Ways to Understand and Train Your Brain for Life*, there's nothing more fascinating than the human brain and the unexpected ways in which it works. Techniques like this to improve focus are at the top of the list.

Or to quote Kounios once more: "As jazz great Charlie Parker said, 'You've got to learn your instrument. Then, you practice, practice, practice. And then, when you finally get up there on the bandstand, forget all that and just wail.'"

1mm-thick speakers could reshape smart glasses, smartwatches, and earbuds

XMEMS, the company that created the first speaker based on a microchip manufacturing processes, is getting set to release its next wave of tiny speakers. Known as Sycamore, the newest model is just 1.13 mm thick, and weighs only 150 milligrams, yet it can reproduce full-range sound over short distances — like the gap between your ears and the limbs of your smart glasses — according to xMEMS.

Sycamore is the latest step in the evolution of micro speakers.XMEMS' first version could be used in wireless earbuds to reproduce high frequencies, but needed the help of a dynamic driver for bass. Its second product could do full-range sound, but was still limited to earbuds that seal the ear canal with a silicone tip. Sycamore is the company's first micro speaker that reproduce full-range sound without the need of a closed, sealed environment.

xMEMS

The company is extolling the many audio benefits of the Sycamore driver as compared to traditional speaker technologies: “With its first-order low-frequency roll-off, it can match mid-bass performance of legacy drivers while offering as much as 11 [decibels] headroom in sub-bass extension. Sycamore also pushes the performance envelope on high-frequency sound — by as much as 15dB above 5KHz over legacy drivers.”

In other words, the Sycamore is expected to produce better lows and highs. It’s also remarkably robust, with an IP58 rating that makes it impervious to water and highly resistant to dust.

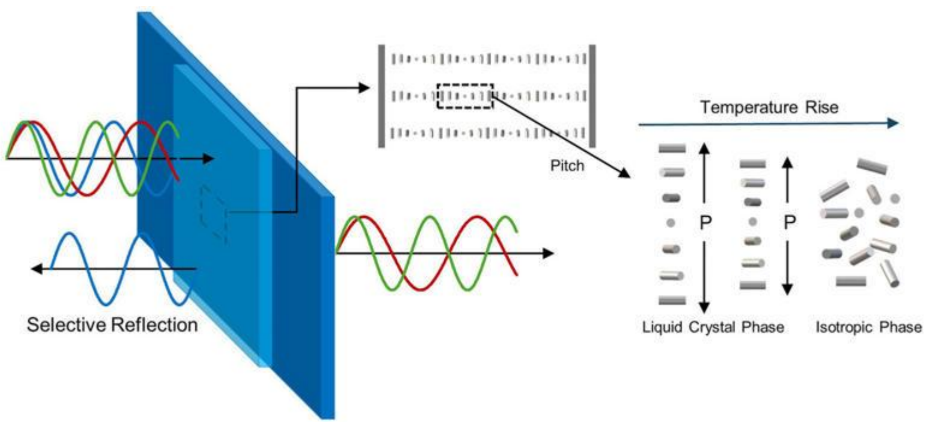
xMEMS

However, it's really Sycamore's size that's expected to spur designers of electronics into creating better products. It's one-seventh the size of a conventional dynamic driver package, according to xMEMS, and one-third the thickness. That difference alone could yield smart glasses with thinner, more fashionable limbs, thinner and more durable smartwatches, and open-ear earbuds that are smaller and sound better.

XMEMS also predicts that there will be other uses for Sycamore. With its high-frequency performance, it could act as a tweeter in automotive headrests, Bluetooth speakers, and laptops. The company thinks it could also yield clearer calls and greater privacy when used as an earpiece speaker in smartphones.

All of this is still speculative. XMEMS won't be releasing Sycamore manufacturing samples to prospective electronics companies until the first quarter of 2025, and says that mass production won't begin until October 2025. Still, with these timelines, we could see the first Sycamore-enabled products announced in time for CES 2026.

Prototype lenses can block epileptic-seizure causing wavelengths



Schematic diagram of a thermal-controlled CLC lens that can reflect certain wavelengths of light. Credit: Cell Reports Physical Science (2024). DOI: 10.1016/j.xcrp.2024.102158

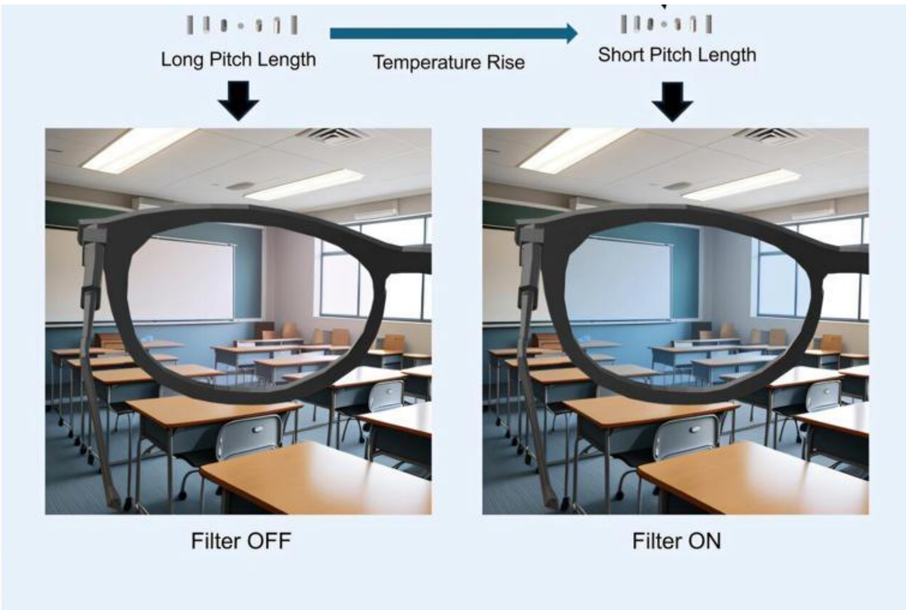
People with photosensitive epilepsy could benefit from a prototype pair of glasses with lenses that block out wavelengths that are known to cause seizures in some people.

In a study published in *Cell Reports Physical Science*, researchers from the University of Glasgow and University of Birmingham have developed a prototype of a liquid crystal lens that they believe could help photosensitive epilepsy sufferers.

The lenses are controlled by very small changes in temperature that can be built into the lens, and when activated can block more than 98% of light in the 660–720nm wavelength range, known to affect the greatest number of people suffering from photosensitive epilepsy.

Zubair Ahmed, Professor of Neuroscience at the University of Birmingham and co-author of the study said, "This is a hugely exciting project that felt like a science fiction project when we first started the work four years ago. This paper demonstrates the potential for the use of liquid crystal lenses that can be modulated to cut out specific wavelengths of light."

"The prototype shows how a discrete circuit installed in the frame of a pair of glasses can power these lenses and be used in situations where a certain wavelength of light is likely to trigger a seizure, such as while watching TV or playing computer games. The circuit heats up the lenses to a comfortable temperature for wearers that will also cut out more than 98% of light with a wavelength that can cause seizures."



Graphical abstract. Credit: Cell Reports Physical Science (2024). DOI: 10.1016/j.xcrp.2024.102158

Rami Ghannam, Professor of Electronics at the University of Glasgow and lead author of the study said, "The project shows how collaboration between different disciplines such as engineering, neuroscience and mathematics can bring about potential discoveries that could transform the lives of patients affected by various diseases."

"We are now developing this protype further to improve its performance before we take this into human studies."

The authors note that the current prototype was functional in rooms up to 26°C temperatures, and further tweaks to the technology would be needed to cater for uses in hotter environments. The team also note that the time taken for the prototype to heat and cool could be improved.

More information: Yuanjie Xia et al, Thermal-controlled cholesteric liquid crystal wavelength filter lens for photosensitive epilepsy treatment, *Cell Reports Physical Science* (2024). DOI: 10.1016/j.xcrp.2024.102158

Provided by University of Glasgow

Daily habits like sleep and exercise can shape brain connectivity for weeks

A new study published in PLOS Biology provides fascinating insights into how our daily experiences and behaviors, such as sleep patterns, physical activity, and even our mood, leave lasting imprints on our brain's connectivity. Conducted by researchers at Aalto University and the University of Oulu, the study used brain scans and data from wearable devices to track the brain activity and physiological states of a single participant over 133 days.

The new findings challenge the common perception that brain connectivity is influenced only by immediate events, revealing instead that behaviors from up to 15 days prior can continue to shape the brain's functional connections. This suggests that short-term fluctuations in our environment and physiological states play a much more sustained role in brain dynamics than previously thought.

The researchers were motivated by the idea that human brains do not function in isolation. Ana Triana, the lead researcher, explained that our behavior and mental states are constantly influenced by a wide range of factors, including our environment, physical health, and emotional experiences. However, much of what is currently known about brain connectivity comes from short-term studies or cross-sectional research, which capture only snapshots of brain activity at a single point in time. These designs, while informative, might miss the more extended and complex effects that daily life has on brain function.

Triana and her team wanted to investigate whether behaviors, moods, and physiological changes like heart rate variability or sleep patterns continue to influence brain activity over a more extended period. This approach could provide a more accurate understanding of how our mental and physical states are intertwined with brain connectivity over days and weeks, rather than just minutes or hours.

"We wanted to go beyond isolated events," Triana said. "Our behavior and mental states are constantly shaped by our environment and experiences. Yet, we know little about the response of brain functional connectivity to environmental, physiological, and behavioral changes on different timescales, from days to months."

The study took a unique approach by focusing on just one participant—Ana Triana herself. Over a period of 133 days, Triana's daily activities, sleep patterns, heart rate, and mood were continuously monitored using wearable devices, including a smartwatch and a ring designed to track physiological data.

"The use of wearable technology was crucial," Triana explained. "Brain scans are useful tools, but a snapshot of someone lying still for half an hour can only show so much. Our brains do not work in isolation."

Additionally, she completed surveys about her mood and experiences twice a day. This data was complemented by functional magnetic resonance imaging (fMRI) scans conducted twice a week, which measured her brain's connectivity in different contexts, including rest, attention tasks, and memory tasks.

Each fMRI scan provided a detailed picture of how different regions of Triana's brain communicated with each other while she performed tasks or simply rested. By combining the fMRI data with the physiological and behavioral data collected through wearables and surveys, the researchers could explore how changes in behavior and physical health impacted brain connectivity over time.

One of the key metrics the study focused on was heart rate variability (HRV), which is an indicator of how adaptable the heart is to changes in the body's physiological state, such as during stress or relaxation. By analyzing this in conjunction with brain scans, the researchers could explore the relationship between physiological health and brain connectivity in real-world conditions.

The study found strong evidence that the brain's connectivity evolves in response to external and internal factors over time, and not just in the immediate aftermath of a given event. For instance, a restless night of sleep or an intense workout from several days ago could still be shaping the way different parts of the brain communicate with each other up to 15 days later.

The research identified two distinct patterns in brain connectivity: a short-term wave lasting about seven days, which likely reflects rapid adaptations to more immediate factors like sleep quality, and a longer-term wave of changes that extends to around 15 days, showing more gradual, lasting effects.

One of the study's more surprising findings was the link between HRV and brain connectivity, particularly during periods of rest. Higher heart rate variability, which typically indicates a better capacity to handle stress, was associated with more efficient communication between brain regions, especially in areas related to attention and memory. This suggests that the body's ability to manage stress may have a lasting effect on the brain's functional architecture, even when the brain is not actively focused on a specific task.

Physical activity also played an important role in shaping brain connectivity. Higher levels of daily movement were associated with stronger connections between brain regions, which could imply that regular exercise supports the brain's ability to stay flexible and adapt to new challenges. On the flip side, days with less physical activity were linked to weaker brain connectivity, particularly in areas responsible for attention and cognitive flexibility.

Interestingly, the researchers found that these effects were not limited to the immediate aftermath of a specific behavior. For example, shifts in mood, sleep quality, or physical activity left lasting imprints on brain connectivity that persisted for days or even weeks. The brain appears to retain a "memory" of these behaviors, allowing them to influence brain function well beyond the moment they occurred.

Limitations and Directions for Future Research

While the study's findings are exciting, they come with important limitations. One major limitation is the fact that the study was conducted with only a single participant, which makes it difficult to generalize the findings to the broader population. While this single-case design allowed the researchers to gather incredibly detailed data over a long period, it's unclear whether the same patterns would be observed in other people. The specific lifestyle, physiological makeup, and emotional responses of the participant might differ significantly from those of others, leading to different results.

Future studies could benefit from a larger sample size to see if these brain-behavior relationships hold across different individuals with varied lifestyles and health conditions. Additionally, while the study focused on the effects of behavior and physiological states on brain connectivity, it did not explore whether changes in brain connectivity could, in turn, influence future behavior or physiological responses. Investigating this bidirectional relationship could offer a more comprehensive understanding of how the brain and body interact over time.

Another direction for future research could be the use of more complex statistical models to explore how different factors, such as sleep, mood, and physical activity, interact with each other to influence brain connectivity. The current study looked at these variables in isolation, but in reality, they are likely to have complex, interdependent effects on the brain's functional networks.

Finally, the researchers pointed out that while they tracked changes over a 15-day period, it is unknown whether behaviors from even further back in time might have an impact on brain connectivity. Future studies could extend the observation period to explore whether certain behaviors or physiological states have even longer-lasting effects on brain function.

"We must bring data from daily life into the lab to see the full picture of how our habits shape the brain, but surveys can be tiring and inaccurate," said study co-author, neuroscientist and physician Nick Hayward. "Combining concurrent physiology with repeated brain scans in one person is crucial. Our approach gives context to neuroscience and delivers very fine detail to our understanding of the brain."

"Linking brain activity with physiological and environmental data could revolutionize personalized healthcare, opening doors for earlier interventions and better outcomes," added Triana.

The study, "Longitudinal single-subject neuroimaging study reveals effects of daily environmental, physiological, and lifestyle factors on functional brain connectivity," was authored by Ana María Triana, Juha Salmi, Nicholas Mark Edward Alexander Hayward, Jari Saramäki, and Enrico Glerean.

The Staggering Complexity of the Human Brain

Why our brains are the most complex structures in the known universe.

Posted September 2, 2023 | Reviewed by Ray Parker

- The human brain has been described as the most complex structure in the known universe.
- The brain contains around 86 billion neurons, 85 billion other cells, and over 100 trillion connections.
- Several hundred-million-dollar research projects failed to fully map the structure of the brain.
- The function of the brain is even more complex than its structure with consciousness as the greatest mystery.

While the Milky Way has more stars than the brain has neurons, the manifold connections and interactions in the brain make it arguably more complex.

Source: theartofsounds2001 | Pixabay

The human brain has been described as the most complex known structure in the universe (Dolan, 2007). The numbers are indeed staggering: Ingenious research methods that examined the almost 1,000 brain regions, and extrapolated the expected density from small samples, estimated the total number of nerve cells—or neurons—in the brain at 86 billion (Azevedo et al., 2009).

Staggering Numbers

On top of this, there are another 85 billion cells that serve various functions in the brain. Even more incredible is that each one of these neurons on average connects to thousands of other neurons, resulting in an estimated 100 trillion connections (Caruso, 2023; Zimmer, 2011).

These connections allow signals to travel between neurons and can function as logic gates, giving it a computing power of one exaflop—that is one quintillion mathematical operations per second (Madhavan, 2023)—that is a billion times a billion or 1 followed by 18 zeros.

And it does all of this in an incredibly efficient way, using only 20 watts of power. In comparison, one of the most advanced supercomputers in the world requires a million times more power (20 megawatts) to reach anything near a similar computing capacity (Madhavan, 2023).

The total length of this complex fiber network is estimated to be around 500,000km or over 310,000 miles long (Science Daily, 2017). Signals inside this network can reach traveling speeds of 431 kmh or 268 mph (Ross, 2011). Such complexity comes at a biological cost: Despite only accounting for around 2 percent of the body's mass, the brain consumes around 20 percent of the body's total energy (Herculano-Houzel, 2012).

Is it really the most complex thing?

A widespread myth is that there are more neurons in the brain than there are stars in the Milky Way. This is not actually true: There are around 200 to 400 billion stars in our galaxy and the commonly cited 100 billion neurons in the brain is probably an overestimation (Stoke & Boytek, 2013). A more accurate figure is around 86 billion (Azevedo et al., 2009).

So, is it really the most complex structure we know of? Many experts still seem to believe so, from physicist Michio Kaku (2014) who described the three pounds in our head as the most complex object in the solar system (pp.2-3), to neuroscientist Christof Koch (2013), psychiatrist Sir Robing Murray (2012), and neurobiologist Gerald Fischbach (1992), who all described it as the most complex structure in the known universe. This is because the complexity is much greater than the number of cells themselves: The many complex connections and the myriad interactions give the brain not only structural complexity but turns it into an intricately functioning whole.

While stars and galaxies interact, they cannot rival the complicated interplay, signaling, and computation going on between neurons.

It is difficult for us to grasp very large numbers, like the number of neurons or connections in the brain. Another way to highlight the complexity of the brain is through something we are more familiar with money, time, and people.

Mapping the Brain

The Human Brain Project was one of the biggest research endeavors the European Union has ever undertaken: It had a budget of €600 million, ran for 10 years, and involved 500 scientists across different institutions (Naddaf, 2023). The goal was to map and then simulate the entire human brain.

Although the project managed to create 3D maps of around 200 brain structures, this represents only a fraction of the initial goal (Naddaf, 2023). Similarly, the US BRAIN project, announced by President Obama in 2013 with an initial funding of $100 million is still ongoing but had to scale back its initial goal of mapping the entire human brain at the level of individual neurons (Mullin, 2023).

Critics have pointed out problems in the management of these projects (Mullin, 2023; Naddaf, 2023) but a key reason for the seeming failure is the underlying complexity of the brain itself.

Hundreds of millions of dollars and over a decade of research by leading scientists have not been able to fully describe the structure of the brain. And understanding the structure of the brain is much simpler than grasping its functioning. A leading neuroscientist wagered in 1998 that the neural mechanisms of consciousness would be discovered within 25 years. He recently conceded his bet lost (Lenharo, 2023).

Remaining Mysteries

Despite the tremendous progress that has been made in understanding the brain, its staggering complexity means that we are still a long way off from fully understanding its structure and even further away from fully understanding the way it functions. Many ancient cultures saw the heart as the seat of thought, emotion, and volition and had little regard for the brain.

In ancient Egypt, for example, the brain was discarded during the mummification process, while the heart was carefully preserved (see Ancient

Concepts of the Mind, Brain (and Soul), Pang, 2023a). We now know that the brain is linked to our thoughts, emotions, and experiences.

Evidence for this includes that damage to the brain impacts those processes (Vaidya et al., 2019), that these processes are congruent with measured electrical activity in the brain, as well as with images taken (for example through functional magnetic resonance images or fMRI; DeSouza et al., 2012), and that psychoactive drugs that target the brain can influence these functions (Buxton et al., 2008).

There is further evidence from developmental psychology and from brain stimulation experiments. Despite the tremendous progress that has been made in neuroscience, psychology, and neurology, many aspects of the brain remain mysterious. The Australian philosopher David Chalmers (1995) suggested that while neuroscience will likely be able to answer most conventional (or what he termed "easy") questions about the brain, the hard problem of why electrical impulses in the brain lead to conscious experience may not be solved (see What is Consciousness? and The Many Dimensions of Consciousness; Pang, 2023b, 2023c).

Conclusion

Our brains are staggeringly intricate and have been described as the most complex structures in the known universe. Despite tremendous advances in neuroscience, many aspects of the brain remain mysterious. Arguably the biggest mystery and the hardest problem to solve is understanding how neural activity gives rise to conscious experiences.

Provided by University of Birmingham

Scientists use Matrix-style learning to 'write' skills into human brain noninvasively

e Matrix-style learning to 'write' skills into human brain noninvasively

A team of researchers from the University of Rochester, Yale University, and Princeton University has made a big stride in neuroscience.

They have shown a method to induce learning through the direct manipulation of brain activity patterns.

This technique uses real-time brain imaging and neurofeedback. It bypasses learning processes that require effort, study, or practice.

“With our method not only can we nudge complex patterns around in the brain toward known ones, but also—for the first time—write directly a new pattern into the brain and measure what effect that has on a person’s behavior,” said Dr Coraline Iordan, lead author of the study and assistant professor of brain and cognitive sciences at the University of Rochester.

Researchers focused on visual learning in their study

Participants were placed in a functional magnetic resonance imaging (fMRI) machine, which allows for the monitoring of brain activity in real-time.

They were then presented with abstract shapes on a screen. These shapes were programmed to “wobble,” and participants were instructed to attempt to stop this movement using only their minds.

The participants did not know that the “wobbling” was connected to their brain activity. The researchers had pre-defined a specific brain activity pattern associated with a new visual category.

When a participant’s brain activity aligned with this target pattern, the wobbling would cease. This feedback mechanism effectively “sculpted” the participants’ brain activity, guiding them toward the desired pattern.

Learning without any conscious awareness

"Instead of teaching you something and measuring how your brain changes, we wrote a new category into your brain that would have appeared had you learned it yourself," explained Iordan.

Through this process, participants successfully learned to recognize new visual categories without any conscious awareness of what those categories were. This shows the brain's ability to learn without effort or instruction.

"One of the striking features of the study is that the neural responses and corresponding behavior to the new categories occurred without explicit awareness of those categories," said Dr Jonathan Cohen, a neuroscientist at Princeton University and co-author of the study.

"We essentially turned learning on its head and taught your brain something that caused you to vicariously gain information, even though you were never explicitly given that information," added Iordan.

Potential applications

This technology has many possible uses. It could change education by speeding up learning, particularly for individuals with learning challenges.

It could also be used for rehabilitation. For example, it could help stroke patients recover brain functions. Additionally, the ability to change brain activity could lead to treatments for mental disorders.

"This study is one of the most powerful demonstrations yet of brain training with real-time fMRI," concluded Dr Nicholas Turk-Browne, a psychologist at Yale University and co-author of the study.

"In the future, this discovery could inform the development of brain-computer interfaces and clinical interventions."

While this technology is still in its early stages, it represents a paradigm shift in our understanding of learning and brain plasticity. Further research is necessary to explore the long-term effects and optimize its application.

This is exciting to physicists. Usually the laws of physics, which are symmetrical across space and (in most cases) time, creating outcomes that are the same regardless of their direction in space and time.
But crystals break this symmetry, arranging themselves in a preferred spatial direction. This means that, even if physical laws are still symmetrical, they create different outcomes depending on the direction they act upon crystals.

In the same way that crystals break symmetry in space, time crystals break them in time. They exist in the lowest possible energy permitted by quantum mechanics, and oscillate between two states without slowing down.

These remarkable properties have led to many claims that time crystals are perpetual motion machines that violate the second law of thermodynamics, but this isn't the case. The crystals, which are driven by lasers, simply cannot lose or gain energy — all the laser light hitting them does is cause them to repeat their two-step shuffle. This means that, like many systems containing only a handful of atoms, the second law does not apply to them.
A number of time crystals have been made since Wilczek's proposal, each offering their own unique windows into this bizarre phase of matter. To build their time crystal, the researchers behind the new study turned to rubidium atoms excited into what are known as Rydberg states.

By firing laser light at a glass container filled with rubidium atoms, the physicists pumped the gas with tons of excess energy. The laser light excited the electrons found within the atoms, causing the spaces between their atomic nuclei and the electrons' outer shells to balloon to hundreds of times their usual size. This made something very interesting happen.

"If the atoms in our glass container are prepared in such Rydberg states and their diameter becomes huge, then the forces between these atoms also become very large," Pohl said. "And that in turn changes the way they interact with the laser. If you choose laser light in such a way that it can excite two different Rydberg states in each atom at the same time, then a feedback loop is generated that causes spontaneous oscillations between the two atomic states. This in turn also leads to oscillating light absorption."

In other words, a time crystal had appeared within the glass box.

"This is actually a static experiment in which no specific rhythm is imposed on the system," Pohl added. "The interactions between light and atoms are always the same, the laser beam has a constant intensity. But surprisingly, it turned out that the intensity that arrives at the other end of the glass cell begins to oscillate in highly regular patterns."

Now that they've created their new type of time crystal, the researchers will continue to experiment on it and test it for further applications. They have suggested that it could be used to create new, highly sensitive sensors, alongside helping scientists to better understand quantum synchronization — a phenomenon in which multiple quantum systems can be made to act in phase, that will aid in the development of better quantum computers.

Quantum secrets

"A time crystal keeps moving and repeats itself periodically in time in the absence of external encouragement," said Autti. This is possible because the time crystal is in its lowest energy state. The basic rules of quantum mechanics prevent the motion from becoming completely still, and so the time crystal remains "stuck" in its never-ending cycle.

"This means they are perpetual motion machines, and therefore impossible," remarked Autti.

The laws of thermodynamics suggest that systems in equilibrium tend toward more entropy, or disorder — a coffee cup sitting out will always cool, a pendulum will eventually stop swinging, and ball rolling on the ground eventually comes to rest. But a time crystal defies that, or simply ignores it, because the rules of thermodynamics don't seem to apply to it. Instead, time crystals are subject to quantum mechanics, the rules that govern the zoo of subatomic particles.
"In quantum physics, a perpetual motion machine is fine as long as we keep our eyes closed, and it must only start slowing down if we observe the motion," Autti said, referring to the fact that the exotic quantum mechanical states required for time crystals cannot keep operating once they interact with their environment (for example, if we observe them).

This implies that physicists can't directly observe time crystals. The moment they try to watch one, the quantum rules that allow them to exist break down, and the time crystal grinds to a halt. And that concept extends beyond observation: Any strong enough interaction with the external environment that breaks down the quantum state of the time crystal will make it stop being a time crystal.

This is where Autti's team came in, trying to find a way to interact with a quantum time crystal through classical observations. At the tiniest scale, quantum physics reigns. But bugs and cats and planets and black holes are better described by the deterministic rules of classical mechanics.

"The continuum from quantum physics to classical physics remains poorly understood. How one becomes the other is one of the outstanding mysteries of modern physics. Time crystals span a part of the interface between the two worlds. Perhaps we can learn how to remove the interface by studying time crystals in detail," said Autti.

Magical magnons

In the new study, Autti and his team used "magnons" to build their time crystal. Magnons are "quasiparticles," which emerge in the collective state of a group of atoms. In this case, the team of physicists took helium-3 — a helium atom with two protons but only one neutron — and cooled it to within a ten-thousandth of a degree above absolute zero. At that temperature, the helium-3 transformed into a Bose-Einstein condensate, where all the atoms share a common quantum state and work in concert with each other.

In that condensate, all the spins of the electrons in the helium-3 linked up and worked together, generating waves of magnetic energy, the magnons. These waves sloshed back and forth forever, making them a time crystal.

Autti's team took two groups of magnons, each one operating as its own time crystal, and brought them close enough to influence each other. The combined system of magnons acted as one time crystal with two different states.

Autti's team hopes that their experiments can clarify the relationship between quantum and classical physics. Their goal is to build time crystals that interact with their environments without the quantum states disintegrating, allowing the time crystal to keep running while it is used for something else. It wouldn't mean free energy — the motion associated with a time crystal doesn't have kinetic energy in the usual sense, but it could be used for quantum computing.

Having two states is important, because that is the basis for computation. In classical computer systems, the basic unit of information is a bit, which can take either a 0 or 1 state, while in quantum computing, each "qubit" can be in more than one place at the same time, allowing for much more computing power.

"This could mean that time crystals can be used as a building block for quantum devices that work also outside the laboratory. In such a venture the two-level system we have now created would be a basic building block," Autti said.

This work is currently very far away from a working quantum computer, but it does open up interesting avenues of research. If scientists can manipulate the two-time-crystal system without destroying its quantum states, they could potentially build larger systems of time crystals that serve as true computational devices.

New solar cell technology could ditch batteries in gadgets for good by harvesting ambient room light

A new solar cell technology designed to recharge devices such as remote controls by harvesting ambient indoor light was just unveiled.

The technology was showcased by California-based Ambient Photonics at CES 2024, with the startup also partnering with Google to incorporate the technology into a new consumer product, which it hasn't yet revealed. They plan to launch it at some point in 2024, company representatives announced at the show.

The company is also working on a solar-powered computer mouse. None of these devices, including the unknown Google product, will require disposable batteries or need to be consciously recharged, according to the company.

The technology in the new cells is bifacial, which means it can harvest and generate energy from both sides, which lets it generate enough energy to power home electronics. Its previous cells were only single-sided, with the rear side providing 50% additional energy on top of the 100% efficiency of the front-facing side.

Inspired by photosynthesis — the process by which plants convert sunlight into energy — these photovoltaic cells contain light-sensitive dye molecules that turn photons, small particles of electromagnetic radiation, into electrons, negative subatomic particles.
This creates a charge differential that, in turn, allows electricity to flow. They work similarly to how chlorophyll, which makes plants green, creates power from photons in photosynthesis.

“In a dye sensitized solar cell, the amount of electrical power produced depends on how effectively the photons are absorbed by the dye," Joshua Wright, vice president of engineering at Ambient Photonics, told Live Science in an email.

Wright claimed his team achieved “superior dye chemistry” for producing “unmatched power density”, with the company publishing more information in a document outlining how its technology works. Ambient's dyes are based on over 40 organic sensitizer molecules — the active component of dye sensitized solar cell (DSSC) technology — which absorb light across the entire visible electromagnetic spectrum, like those in other solar panels.
Reducing the need for batteries could cut electronic waste, as TK billions of batteries go to landfills every year.

Although solar power technology has existed for decades, generating enough power for devices at low lighting levels has been a vexing problem. Previous attempts to create low-lighting solar cells haven't been sufficient, with Wright explaining that traditional photovoltaic innovations such as amorphous silicon cells "don’t yield sufficient power in the real-world, low-light operations conditions."

Ambient claims its technology harvests three times more light than comparable solutions.

"Also, the large price tag on high performance, low-light photovoltaic technologies like gallium arsenide cells has made them suitable only for space satellite and research applications, not mass-market electronics," he said.

Australian breakthrough: New smartphone battery could triple lifespan

Will charging the battery become a thing of the past?© Pexels, Iurii Laimin

Australian scientists have introduced an innovative type of battery designed for smartphones. They claim that the new battery will be more durable and suitable for reuse, potentially extending its lifespan up to three times.

If the predictions of Australian researchers are realized, smartphone replacements could become less frequent in the future. Many users are familiar with the issue where **the phone's battery loses its efficiency after about two or three years, causing the device to discharge quickly.** The new batteries being developed are not only expected to last longer but also to be more recycling-friendly.

Are we on the brink of a smartphone battery revolution?

In their research, specialists highlight that **only 10% of used phones in Australia are recycled.** A similar situation exists in other parts of the world because processing devices with lithium-ion batteries is complicated and not cost-effective. To address this, scientists from RMIT in Melbourne used MXene—a compound comparable to graphene with high electrical conductivity—instead of lithium.

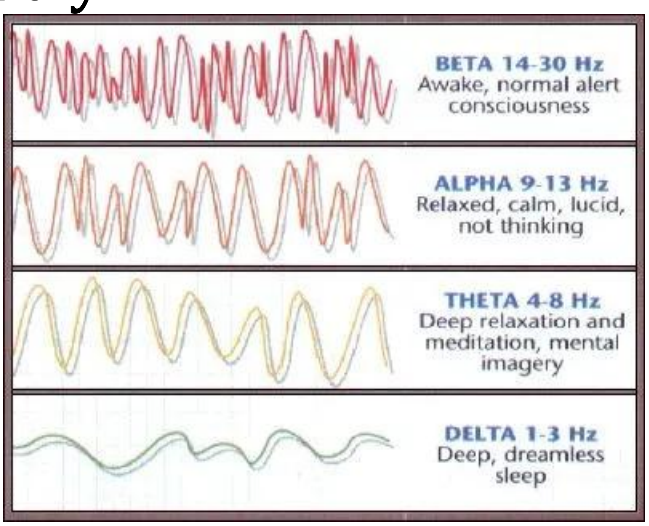
Although MXene rusts over time, engineers from RMIT have found a way to solve this problem. Tests have shown that exposing the battery to sound waves at a frequency of 10 Hz for a minute effectively removes rust, allowing the battery to be reused.

How long will the new battery last?

This process can be repeated twice, meaning that with the standard battery life in smartphones being about three years, new MXene batteries could last up to nine years.

Of course, this assumes that other smartphone components operate flawlessly. Even if the new batteries do not allow for less frequent phone changes, **the introduction of such a solution is a step towards more efficient battery recycling.** Ultimately, this could help reduce the amount of electronic waste. Researchers are already seeking business partners interested in implementing this technology in the market.

Scientists use Matrix-style learning to 'write' skills into the human brain noninvasively



A team of researchers from the University of Rochester, Yale University, and Princeton University has made a big stride in neuroscience.

They have shown a method to induce learning through the direct manipulation of brain activity patterns.

This technique uses real-time brain imaging and neurofeedback. It bypasses learning processes that require effort, study, or practice.

“With our method not only can we nudge complex patterns around in the brain toward known ones, but also—for the first time—write directly a new pattern into the brain and measure what effect that has on a person’s behavior,” said Dr Coraline Iordan, lead author of the study and assistant professor of brain and cognitive sciences at the University of Rochester.

Researchers focused on visual learning in their study

Participants were placed in a functional magnetic resonance imaging (fMRI) machine, which allows for the monitoring of brain activity in real-time.

They were then presented with abstract shapes on a screen. These shapes were programmed to “wobble,” and participants were instructed to attempt to stop this movement using only their minds.

The participants did not know that the “wobbling” was connected to their brain activity. The researchers had pre-defined a specific brain activity pattern associated with a new visual category.

When a participant’s brain activity aligned with this target pattern, the wobbling would cease. This feedback mechanism effectively “sculpted” the participants’ brain activity, guiding them toward the desired pattern.

Learning without any conscious awareness

“Instead of teaching you something and measuring how your brain changes, we wrote a new category into your brain that would have appeared had you learned it yourself,” explained Iordan.

Through this process, participants successfully learned to recognize new visual categories without any conscious awareness of what those categories were. This shows the brain’s ability to learn without effort or instruction.

“One of the striking features of the study is that the neural responses and corresponding behavior to the new categories occurred without explicit awareness of those categories,” said Dr Jonathan Cohen, a neuroscientist at Princeton University and co-author of the study.

“We essentially turned learning on its head and taught your brain something that caused you to vicariously gain information, even though you were never explicitly given that information,” added Iordan.

Potential applications

This technology has many possible uses. It could change education by speeding up learning, particularly for individuals with learning challenges.

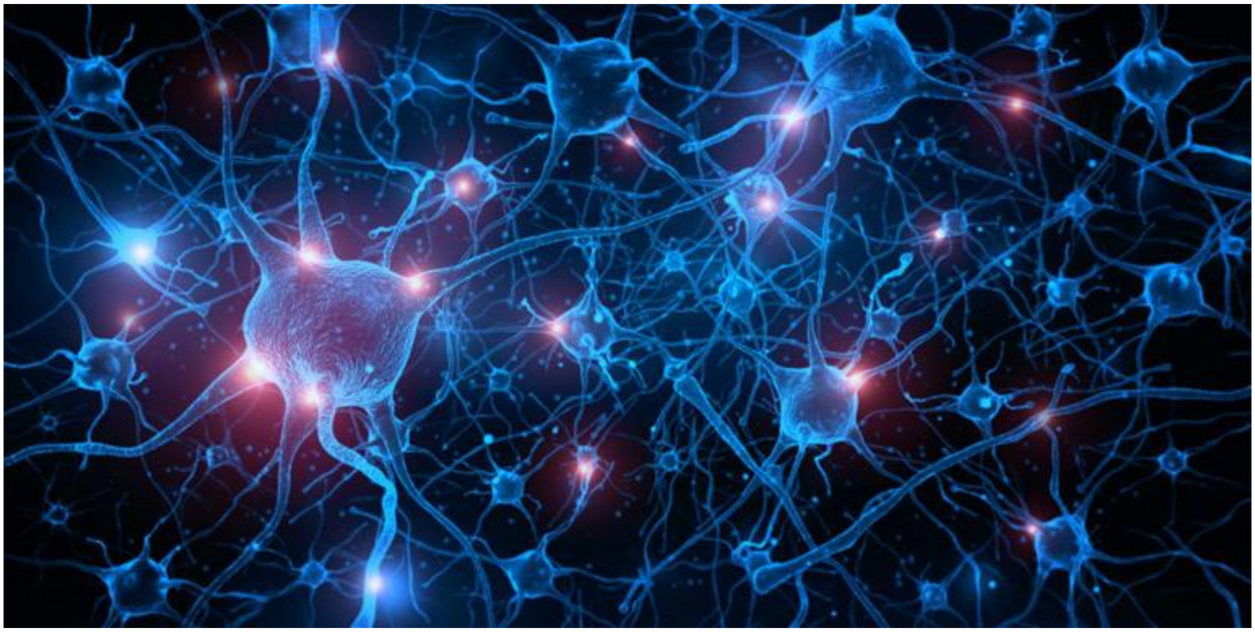
It could also be used for rehabilitation. For example, it could help stroke patients recover brain functions. Additionally, the ability to change brain activity could lead to treatments for mental disorders.

“This study is one of the most powerful demonstrations yet of brain training with real-time fMRI,” concluded Dr Nicholas Turk-Browne, a psychologist at Yale University and co-author of the study.

“In the future, this discovery could inform the development of brain-computer interfaces and clinical interventions.”

While this technology is still in its early stages, it represents a paradigm shift in our understanding of learning and brain plasticity. Further research is necessary to explore the long-term effects and optimize its application.

How neurons work together: A fractal approach to brain efficiency


(Photo credit: Adobe Stock)© PsyPost

The brain is a marvel of efficiency, honed by thousands of years of evolution so it can adapt and thrive in a rapidly changing world. Yet, despite decades of research, the mystery of how the brain achieves this has remained elusive.

Our new research, published in the journal *Cell*, reveals how neurons – the cells responsible for your childhood memories, thoughts and emotions – coordinate their activity.

It's a bit like being a worker in a high-performing business. Balancing individual skills with teamwork is key to success, but how do you achieve the balance?

As it turns out, the brain's secret is surprisingly simple: devote no more than half (and no less than 40%) of each cell's effort to individual tasks. Where does the rest of the effort go? Towards scalable teamwork.

And here's the kicker: we found the exact same organisational structure across the brains of five species – from fruit flies and nematodes to zebrafish, mice and monkeys.

These species come from different branches of the tree of life that are separated by more than a billion years of evolution, suggesting we may have uncovered a fundamental principle for optimised information processing. It also offers powerful lessons for any complex system today.

The critical middle ground

Our discovery addresses a long-standing debate about the brain: do neurons act like star players (each highly specialised and efficient) or do they prioritise teamwork (ensuring the whole system works even when some elements falter)?

Answering this question has been challenging. Until recently, neuroscience tools were limited to either recording the activity of a few cells, or of several million.

However, with advances in calcium imaging, we can now record signals from tens of thousands of cells simultaneously. Calcium imaging is a method that lets us watch neural activity in real time by using fluorescent sensors that light up according to calcium levels in the cell.

Applying insights from my physics training to analyse large-scale datasets, we found that brain activity unfolds according to a fractal hierarchy. Cells work together to build larger, coordinated networks, creating an organisation with each scale mirroring those above and below.

This structure answered the debate: the brain actually does *both*. It balances individuality and teamwork, and does so in a clever way. Roughly half of the effort goes to "personal" performance as neurons collaborate within increasingly larger networks.

By contrast, mouse vision adapts at the cellular scale, permitting the precision required to extract fine details from a scene. Here, if a few neurons miss key pieces of information, the entire perception can shift – like when an optical illusion tricks your brain.

Our findings reveal that this fractal coordination of neuron activity occurs across a vast evolutionary span: from vertebrates, whose last common ancestor lived 450 million years ago, to invertebrates, dating back a billion years.

This suggests brains have evolved to balance efficiency with resilience, allowing for optimised information processing and adaptability to new behavioural demands. The evolutionary persistence hints that we've uncovered a fundamental design principle.

A fundamental principle?

These are exciting times, as physics and neuroscience continue interacting to uncover the universal laws of the brain, crafted over aeons of natural selection. Future work will be needed to see how these principles might play out in the human brain.

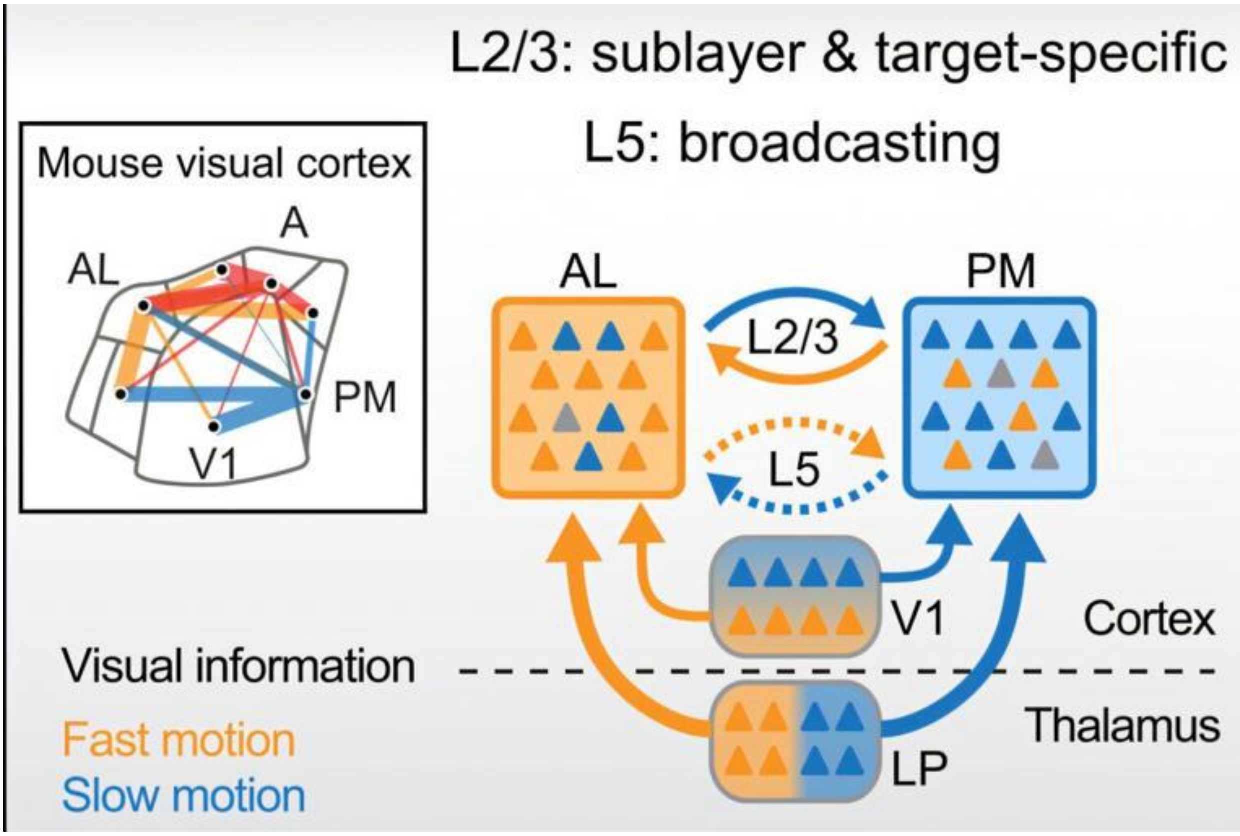
Our findings also hint at something bigger: this simple rule of individual focus and scalable teamwork might not just be a solution for the brain.

When elements are organised into tiered networks, resources can be shared efficiently, and the system becomes robust against disruptions.

The best businesses operate in the same way — when a new challenge arises, individuals can react without waiting for instructions from their manager, allowing them to solve the problem while remaining supported by the organization rapidly.

It may be a universal principle to achieve resilience and efficiency in complex systems. It appears basketball legend Michael Jordan was right when he said: "talent wins games, but teamwork and intelligence win championships".

Researchers discover new connectivity rules in the brain's visual network



Graphical abstract. Credit: Current Biology (2024). DOI: 10.1016/j.cub.2024.10.048

Researchers at Neuro-Electronics Research Flanders (NERF), led by Prof. Vincent Bonin, have published two studies uncovering how visual information is processed and distributed in the brain. The studies reveal the complexity and flexibility of visual information processing in the brain.

The visual cortex, a key region for interpreting and processing visual input, plays a crucial role in shaping what we see. Vincent Bonin, a professor at KU Leuven and group leader at NERF, studies the neural circuits that process sensory information.

"We often think of visual processing in the cortex as a simple, linear process," explains Prof. Bonin, "but our research shows the cortex operates as a complex network with finely tuned connections between regions, supporting specialized visual functions across distinct brain areas."

Targeting vs. broadcasting

In a first study published in *Current Biology*, postdoctoral researcher Xu Han revealed how visual information is transmitted across different interconnected regions in the brain.

Using advanced imaging and circuit-tracing techniques in mice, Han and Bonin identified pathways that either selectively channel visual signals to targeted areas or broadcast information broadly across multiple regions.

"For instance, neurons in the pulvinar and certain layers of the cortex are finely tuned to their targets, suggesting a role in constructing detailed visual representations," explains Han.

"In contrast, deeper neurons seem to ignore target specificity, broadcasting similar visual information across areas—possibly for coordinating broader brain activity." These findings challenge the long-held belief that visual information flows in a simple, step-by-step manner, instead revealing a highly dynamic and adaptable network.

Quiet vs. aroused

In the second study, published in *Cell Reports*, Bonin and Dr. Karolina Socha (now at the University of California in LA) explored how the brain's thalamus—a key relay station for visual signals—adjusts information processing depending on behavioral states.

The researchers found that during quiet wakefulness, neurons in the thalamus amplify signals for back-to-front motion, a transformation absent under anesthesia or heightened arousal. By imaging the activity of neurons in awake mice, they discovered that this modulation is linked to changes in pupil size, a marker of arousal.

"Larger pupils coincided with stronger responses to back-to-front motion, suggesting that the thalamus integrates sensory inputs with behavioral context to prioritize certain visual stimuli," explains Bonin. "These findings demonstrate how the thalamus integrates behavioral context to dynamically shape visual representations, altering how motion is processed and prioritized."

Together, both studies represent a major step toward creating a detailed "functional-anatomical map" of the brain's visual system. "Understanding these pathways and mechanisms allows us to predict and manipulate how perception works," says Bonin.

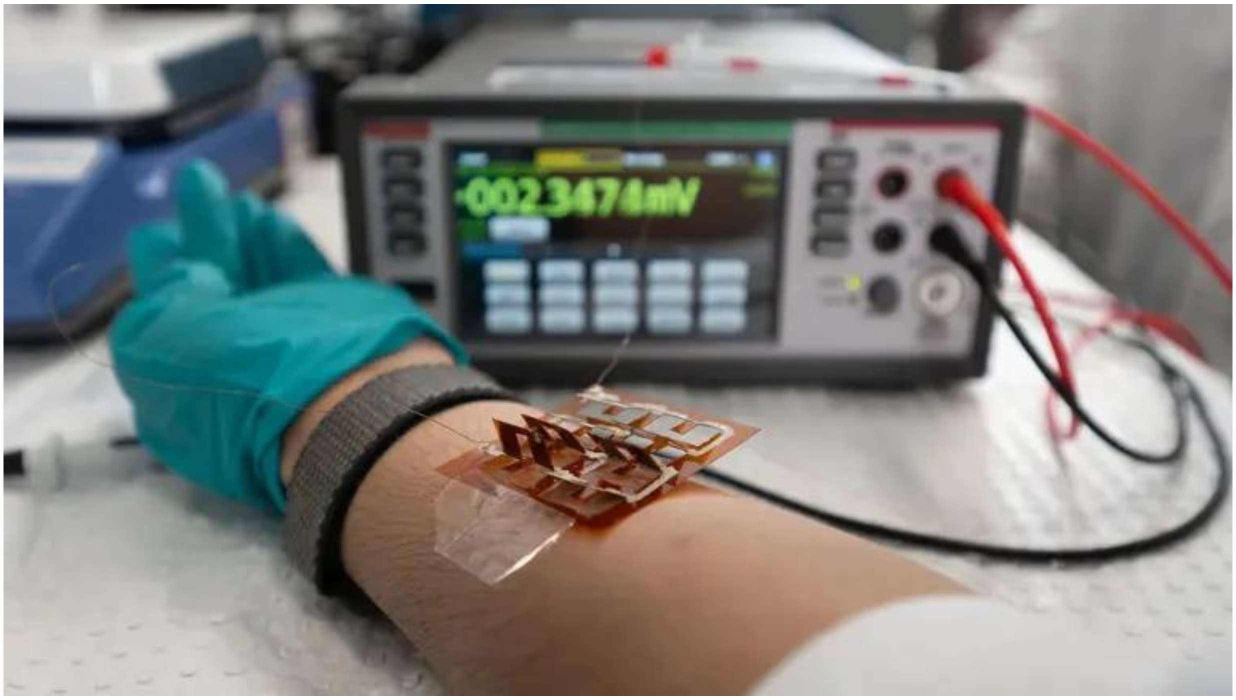
These findings advance neuroscience research and hold promise for developing targeted interventions to modulate brain function.

More information: Xu Han et al, Higher-order cortical and thalamic pathways shape visual processing streams in the mouse cortex, *Current Biology* (2024). DOI: 10.1016/j.cub.2024.10.048

Karolina Z. Socha et al, Behavioral modulations can alter the visual tuning of neurons in the mouse thalamocortical pathway, *Cell Reports* (2024). DOI: 10.1016/j.celrep.2024.114947.

Provided by VIB (the Flanders Institute for Biotechnology)

Body Heat Could Power Next Generation of Wearable Devices, Marking New Battery Era



Body Heat Could Power Next Generation of Wearable Devices, Marking New Battery Era

Why it matters: Scientists have developed flexible thermoelectric devices that convert body heat into electricity, potentially eliminating the need for traditional batteries in wearable technology. As reported by PopSci, this breakthrough comes as the global battery industry undergoes massive transformation to meet growing energy storage demands.

The Big Picture: According to The Hustle, researchers at Queensland University of Technology and the University of Washington have created innovative materials that harness body heat:

- Uses nanobinder crystals and bismuth telluride sheets
- Generates enough power to run LED lights
- Enables battery-free medical devices
- Creates self-powered smart clothing

Healthcare Applications: The technology could revolutionize medical devices:

- Continuous glucose monitoring without battery changes
- Self-powered pacemakers
- Uninterrupted health tracking
- Enhanced patient comfort and safety

Broader Energy Transition: This development coincides with massive growth in battery technology:

- Lead-acid battery market projected to reach $59 billion by 2032
- Electric car registrations hit 14 million globally in 2023
- Lithium-ion battery demand growing at 15.5% annually
- Battery costs declining through economies of scale

Looking Forward: The technology could expand beyond wearables to cool data centers and power virtual reality systems, marking a significant step toward sustainable electronics like the best smart watches and reduced environmental impact.

The Speed Of Human Thought Estimated At A Puzzling 10 Bits Per Second

A duo of researchers at Caltech have attempted to quantify the speed of human thought, putting it at a somewhat perplexing 10 bits of information per second. To put that into perspective, one estimate of the slowest average download speed in the USA in 2024 clocked in at 93 megabits per second (Mbps), though the amount of information conveyed is lower.

First up, what are we talking about here? Your thoughts may (surprisingly slowly, it turns out) assume that we are talking about the "bits" we see in everyday computing. In computing terms, a bit can have one of two values, often represented by a binary digit, either one or zero. But that doesn't correspond to the amount of information conveyed, sometimes referred to as a "Shannon" after Claude Shannon, often referred to as the "father of information theory".

"To understand the concept of information, it is essential to differentiate it from that of data. Let's take an example. I have a friend who has just given birth. I send her a text message to ask her the sex of the newborn. In my vision of things, there is an equal chance that it will be a boy or a girl. Her response will therefore send me exactly one Shannon. To answer me, she will probably send me a sentence made up of several characters, each represented by several bits. I will therefore receive several dozen bits of data for a single Shannon," Vincent

Gripon, Associate Professor at Télécom Bretagne, explains in a translated piece for The Conversation.

"Our brain is accustomed to this fact. It is estimated that one hundred million bits per second of data are transmitted from the visual cortex to the deep areas of our neocortex. Most of this data is completely useless to us, and moreover carries very little information."

Scientists studying information theory have attempted to quantify the information of various systems, including how much information is conveyed in each syllable of language and how much information there is in the entire visible universe. In doing so, they have hit upon a bit of a puzzle: Our brains are constantly bombarded with sensory data at an incredible rate, estimated to be 10 bits per second, and yet our conscious thoughts process information at a far slower rate.

Human thought, as you might expect, is a difficult thing to quantify. Attempting to do so, the authors of a new study looked at tasks performed by humans and the amount of information processed during it. For example, they looked at the task of manually typing out a hand-written manuscript.

"An advanced typist produces 120 words per minute. If each word is taken as 5 characters, this typing speed corresponds to 10 keystrokes a second. How many bits of information does that represent? One is tempted to count the keys on the keyboard and take the logarithm to get the entropy per character, but that is a huge overestimate. Imagine that after reading the start of this paragraph you are asked what will be the next let..." the team writes in their paper.

"English contains orderly internal structures that make the character stream highly predictable. In fact, the entropy of English is only ~ 1 bit per character. Expert typists rely on all this redundancy: If forced to type a random character sequence, their speed drops precipitously."

From this, they were able to estimate that the speed of thought the typist operates at when typing a random character sequence is around... 10 bits per second. Looking at other tasks, from playing *Tetris* to solving Rubix Cubes in controlled conditions, and listening to English, the team estimated that most of these tasks take place at a similar, surprisingly slow, rate.

"This is an extremely low number," Markus Meister, co-author of the paper, said in a statement. "Every moment, we are extracting just 10 bits from the trillion that our senses are taking in and using those 10 to perceive the world around us and make decisions. This raises a paradox: What is the brain doing to filter all of this information?"

While our brains deal with an avalanche of sensory data, our conscious thoughts appear to operate at a far slower rate. The team notes that this could have implications, for example, in the field of creating brain-computer interfaces. While we (and by we, we mean tech bros) may dream of creating brain-computer interfaces to speed up human brainpower, it could turn out that we are limited by the speed of our own cognition, like trying to connect to fiber optic internet through a Game Boy – your hardware will limit what you can get out of it.

More generally, it raises a number of questions about human cognition, such as why our nervous system can process thousands of items in parallel, while our conscious thought chugs along at such a slow pace.

"How can humans get away with just 10 bits/s? The tautological answer here is that cognition at such a low rate is sufficient for survival," the team writes. "More precisely, our ancestors have chosen an ecological niche where the world is slow enough to make survival possible. In fact, the 10 bits/s are needed only in worst-case situations, and most of the time our environment changes at a much more leisurely pace."

While an interesting estimate of the information speed in human thought, the team stresses that it raises more questions than it answers, offering an avenue for further exploration in the future.

"In particular, our peripheral nervous system is capable of absorbing information from the environment at much higher rates, on the order of gigabits/s," the team writes. "This defines a paradox: The vast gulf between the tiny information throughput of human behavior, and the huge information inputs on which the behavior is based. This enormous ratio – about 100,000,000 – remains largely unexplained."

The study is published in the journal Neuron00808-0).

Neuroscientists discover interactions between brain waves and nerve cells during human memory processes

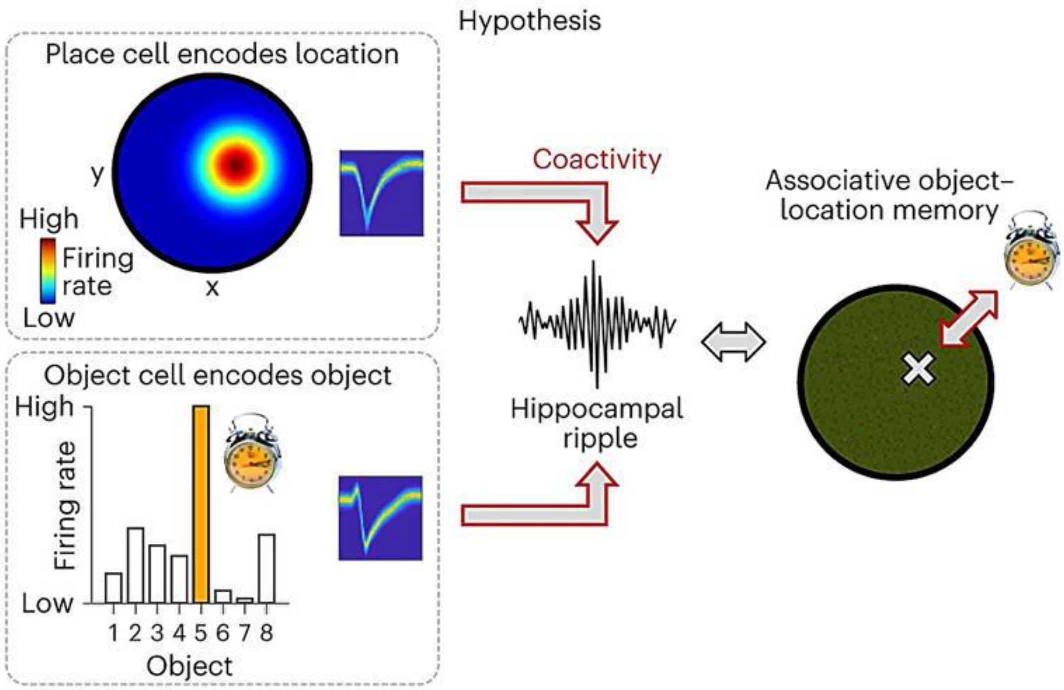


Illustration of the hypothesis that human associative object–location memory is linked to the coactivity of object cells and place cells during hippocampal ripples. We propose that the coactivity is specific to pairs of object and place cells that encode 'associative information', which are those cell pairs in which the location of the preferred object of the object cell is inside the place field of the place cell. Credit: Nature Neuroscience (2024). DOI: 10.1038/s41593-023-01550-x© Provided by Medical Xpress

Spatial navigation and spatial memory play a central role in our lives. Without these abilities, we would hardly be able to find our way around and it would be difficult to remember past events. However, the neuronal basis of spatial memory is far from being fully understood.

A research group led by Prof. Dr. Dr. Lukas Kunz, who has recently joined the University Hospital Bonn (UKB), has gained new insights into this gap in knowledge. Together with scientists from New York and Freiburg, he has discovered that different types of nerve cells become active together during spatial memory and are coordinated by brain waves ("ripples").

These results have now been published in the journal *Nature Neuroscience*.

Associative memory ensures that different pieces of information are linked together. "In the context of spatial memory, associative memory enables us to remember the locations of certain objects in the spatial environment," explains Prof. Kunz, research group leader for Cognitive and Translational Neuroscience at the Department of Epileptology at the UKB. He is also a member of the

.

Nerve cells play an important role in associative memory

Nerve cells are active while information is being retrieved from memory. To further investigate this phenomenon, the researchers recorded the activity of individual nerve cells in the brains of epilepsy patients while they performed a memory task on the computer. "In a virtual world, the test participants were asked to remember the locations of various objects," explains Prof. Kunz.

The recordings showed that different types of nerve cells became active during this memory task. Some nerve cells responded to certain objects, while other nerve cells reacted in response to certain locations. The scientists observed that the interactions between these different types of nerve cells became stronger over time when the test participants remembered the right object in the right place.

Brain waves occur simultaneously, coordinate the nerve cells

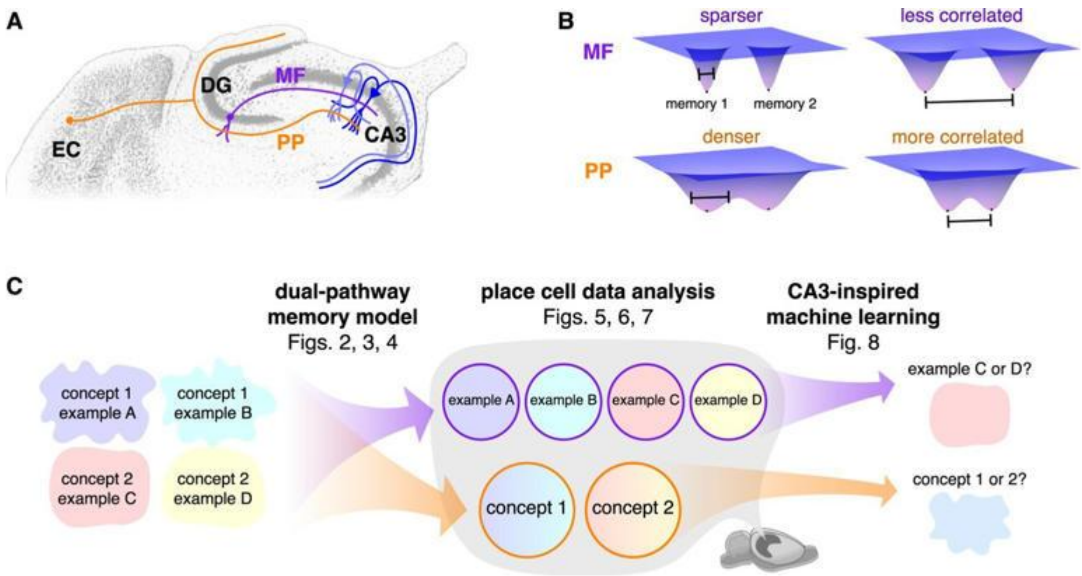
In addition to place and object neurons, the researchers observed that hippocampal brain waves ("ripples") also became active during the memory task, and thus presumably play a crucial role in the formation and retrieval of associative memories.

"Ripples could be important for the connection of different types of nerve cells and the formation of complex memories. It will be exciting to investigate this idea further in future studies," explains Prof. Kunz. It will also be interesting in the future to study how memory performance is modulated when ripples are suppressed or even triggered, providing insights into the causal relevance of ripples.

More information: Lukas Kunz et al, Ripple-locked coactivity of stimulus-specific neurons and human associative memory, *Nature Neuroscience* (2024). DOI: 10.1038/s41593-023-01550-x

Provided by University Hospital of Bonn

Hippocampus uses dual pathways for memory storage



Overview and motivation. Credit: Nature Communications (2024). DOI: 10.1038/s41467-024-44877-0© Provided by Medical Xpress

The mechanism by which our brains record events in stereo—with one channel recording details and another recording general impressions—has been elicited by two RIKEN neuroscientists.

Our memories have two aspects to them: they allow us to recall specific episodes from the past, but they also enable us to draw general concepts from them. For example, we can recall the specifics about a recent visit to see a friend, but we can also extract generalizations about their appearance and personality.

The brain region known as the hippocampus is responsible for both abilities, but just how it manages to do this has been unclear.

Louis Kang of the RIKEN Center for Brain Science (CBS) has long been interested in how memories are stored in the hippocampus. "The hippocampus has always fascinated me," he says. "I think the origin of memories is quite mysterious, even now."

Interestingly, the hippocampus receives two inputs: one in which experiences arrive directly from the brain region upstream from it; and another where it makes a detour through another brain region, where it undergoes processing.

Kang and Taro Toyoizumi, also of CBS, wondered whether the direct pathway that signals information with dense neural activity represents memories with general impressions, while the other one that does so with sparse activity represents all their details.

To test this conjecture, they used techniques from statistical physics (both researchers share a background in physics) to create a mathematical model of neural circuits in the hippocampus. The pair then tested the model using images of three items of clothing: sneakers, trousers and coats. They found that the first pathway stored the details of each image, while the second one generated general conceptual images of each kind of clothing.

Their work has been published in *Nature Communications* and *Physical Review E*.

At this stage, the model provided a plausible description of what could be happening in the hippocampus, but more evidence was needed to support it. "Our model proposed one possible explanation for how the brain remembers both example-like and concept-like memories," says Kang. "But other explanations were also possible."

To obtain further confirmation, the researchers tested their model using experimental recordings of the neurons in the mouse hippocampus that were freely available online. They noticed a signature generated by the model was also present in the recordings. "This supports the possibility that the brain behaves according to our model," says Toyoizumi.

Finally, the two researchers applied the same approach to machine learning, so that neural networks represent information in both example-like and concept-like forms. This resulted in improved performance when distinguishing between similar images and identifying their common features.

"This work shows how biological intelligence can inspire better algorithms for artificial intelligence," notes Kang.

More information: Louis Kang et al, Distinguishing examples while building concepts in hippocampal and artificial networks, *Nature Communications* (2024). DOI: 10.1038/s41467-024-44877-0

Louis Kang et al, Hopfield-like network with complementary

Scientists Want To Entangle Human Brains With Quantum Computers To Learn About Consciousness

A team of researchers believe they may have a way of testing the hypothesis that consciousness in humans arises from entanglement within our brains. To do so would involve creating interfaces between human brains and quantum computers, and attempting to measure any resulting changes in consciousness.

Consciousness is something we all have, but know surprisingly little about. We know how to turn it off with anesthetics, but we aren't really sure how they work either. There are plenty of people working on the problem, but we still don't know whether consciousness is the result of integration within a system (known as integrated information theory) or the result of information being shared across the brain (global workspace theory), the two leading ideas. With so little known, there is room for other, more out-there ideas.

In 1989, British mathematician and Nobel Prize in Physics winner Roger Penrose did just that, suggesting that quantum entanglement is involved in consciousness. Though we cannot summarize his full argument, spread out over several books, the gist of it boils down to the idea that there are some problems that cannot be completed or comprehended by traditional computers. Humans can deal with these problems and comprehend them, such as non-computable numbers and Gödel sentences, and so the human mind must not operate like a traditional computer. Instead, Penrose suggests that consciousness could arise from quantum entanglement within the brain.

The argument, which was not well met at the time, has actually seen a bit of a revival in recent years, though it remains on the fringes of consciousness research. One limit on the idea was that quantum entanglement is fragile and easily broken even at low temperatures, so how could we produce and maintain entanglement in the warm mushy environment of our brains?

But since then, it has been suggested that microtubules inside neurons could provide this stable environment for entanglement. Earlier this year, one team claimed that they had found supporting evidence of this idea, after giving rats microtubule-binding drugs and finding that it then took longer for anesthesia to knock them out, suggesting that they played a role in consciousness.

While further study in that area may give us further clues to what consciousness is and how it works, another team has a far wackier idea for testing whether consciousness is a quantum process. This team, which includes Hartmut Neven, lead of Google's Quantum AI lab, makes the assumption that Penrose is wrong in his suggestion that consciousness arises at the point of superposition collapse, instead suggesting it could arise when it formed, in order to sidestep the absurd possibility of faster-than-light communication in the brain.

The team suggests that the way to test this theory of consciousness is to try to "expand" our own consciousness using an interface between our brains and a quantum computer.

"In an experimentum crucis, one would establish a physical link between a human brain and a quantum computer that would enable coherent interactions and mediate entanglement. If our conjecture is accurate, this should enable richer conscious experiences of the combined system, requiring more descriptive bits than the experiences the human reports without the link," the team explains in their paper, adding that it requires coupling a system within the brain with qubits in superposition inside a quantum computer.

"Before the systems are coupled, their respective states exist in separate state spaces, known as Hilbert spaces, of dimension N and M, respectively. After they are made to interact, the wave function describing the combined system | resides in an × -dimensional Hilbert space," the team writes. "We conjecture that a superposition forming in this higher dimensional state space would be experienced by the subject as a richer experience as compared to a superposition state forming in the lower N-dimensional Hilbert space describing the isolated brain of the subject."

Talking to New Scientist, Neven elaborated on how that would work.

"Let’s say we have 'N' qubits in our brain and 'M' qubits in an external quantum computer, with the letters referring to a certain number of qubits. If a person could entangle their brain with this quantum computer, they could create an expanded quantum superposition involving 'N+M' qubits," Neven said. "If we now tickle this expanded superposition to make it collapse, then this should be reported by the person participating in this experiment as a richer experience. That’s because in their normal conscious experience, they typically need 'N' bits to describe the experience, but now they need 'N+M' bits to describe it."

"I call this the 'expansion protocol', as it would allow us to expand consciousness in space, time and complexity."

According to Neven, reports of richer experiences in these circumstances would offer evidence that consciousness is a quantum phenomenon. While a neat idea, there the test would rely on being able to couple activity in somebody's brain to a quantum computer, which would be an invasive procedure and is not going to happen any time soon.

As well as this, there are many other ideas on consciousness with promise too, many of which don't rely on such invasive procedures. As the team notes, research into inert gases such as xenon and their effect on consciousness may be more fruitful in the meantime.

The study is published in Entropy.

What's the Difference Between Your Left Brain and Right Brain?

Medically reviewed by Dakari Quimby, PhDMedically reviewed by Dakari Quimby, PhD

Have you ever heard people refer to themselves as “left-brained” or “right-brained?” It's a common belief that people with a left brain are more analytical and logical, while people who favor their right brain tend to be more creative and intuitive. While everyone has certain personality traits influenced by the brain, the theory that people favor one side of their brain is a myth. Regardless of your unique or dominant traits, both sides of your brain are necessary for your overall well-being.

Characteristics and Functions of Each Side

People traditionally think of the left brain's function as being focused on logic and reason. People who consider themselves left-brained often believe their ability to be logical and objective is related to their left brain being more active than their right. The left hemisphere is responsible for processing language and numbers and is active during critical thinking and reasoning.

The right side of the brain, however, is responsible for the senses, like vision and hearing, memory, and cognition (thinking). The right brain may also be more active during creative tasks, which is why people who are naturally more artistic consider themselves right-brained.

In reality, the left and right sides of the brain work together. Consider these examples of language and mathematical analysis.

While the left brain specializes in language, the right brain is involved too. The left side of the brain picks up on the sounds of words, and the right side tunes into the emotional features of words and language. This means that both sides of your brain are active and communicating when you process language or talk with another person.

Most people also think the left brain is responsible for solving math equations. While this is true, the right brain helps with spatial awareness and understanding the value of numbers, making analysis easier to process.

Is One Side More Dominant?

The brain acts as the command center for the body, and billions of neurons connect both sides. Both sides of the brain actually work together during most tasks and are connected by brain fibers. There is no scientific evidence that one side of the brain is more dominant. Rather, each hemisphere has unique abilities.

Despite this finding, many people still believe one side of their brain is more dominant. One study estimated that up to 68% of adults in the United States believe that people favor one side of their brain or that one side is more dominant. So, where does this myth come from?

The theory originated from the work of psychologist Roger W. Sperry, who studied people who had their corpus callosum surgically cut. The corpus callosum is the brain structure that connects the two hemispheres of the brain. The people being studied had this structure surgically cut as part of their treatment for uncontrolled epilepsy, which causes seizures.

Sperry determined that each side of the brain had specific functions based on the changes experienced by the study participants. However, the idea that one side of the brain is dominant and entirely responsible for one's personality and strengths has never been proven.

In general, the left hemisphere controls much of the brain's language and logic skills, while the right hemisphere controls spatial awareness and visual understanding. Even though one side of the brain may be more active during certain tasks or functions, they are both necessary.

Tips for Boosting Brain Health

Because both sides of your brain are so important to your well-being, it's essential to promote overall brain health and stay sharp, especially as you age. Both sides of your brain may benefit from the following lifestyle approaches:

- **Exercise daily:** Physical activity has a protective effect on the brain and may boost alertness
- **Eat nutritious foods:** Focus on fresh fruits and vegetables, lean proteins, healthy fats, and whole grains to sustain brain power and mental health
- **Rest well:** Aim to get seven to eight hours of sleep each night to maintain optimal brain function
- **Stay connected:** Social support and relationships are essential for brain health, so it's important to maintain healthy relationships and lean on your network
- **Give your brain a workout:** Challenging your brain through reading, word games, math problems, or puzzles keeps your brain stimulated and functioning
- **Avoid smoking:** Quit or avoid smoking tobacco, as excess use can increase your risk of neurological conditions, among other chronic illnesses

A Quick Review

Several pathways connect the left and right sides (hemispheres) of the brain and work together. In the past, people believed that one side of the brain was more dominant than the other. Left-brained people were considered more objective and logical, while right-brained people were seen as creative, artistic, and intuitive. However, no scientific evidence supports the belief that one side is more important or dominant, as both sides are necessary for most tasks and overall well-being.

DEAR READER,

THIS IS AN AUTOMATED MESSAGE FROM YOUR PREFRONTAL CORTEX

We regret to inform you that your brain has gone offline. Possible causes include:

- **Excessive Netflix binging**
- **Acute caffeine deficiency**
- **Exposure to reality TV**
- **Reading too many emails about neuroscience**

PLEASE STANDBY FOR EMERGENCY REBOOT SEQUENCE

…

…

…

REBOOT FAILED

INITIATING CONTINGENCY PLAN OMEGA

Hello, DEAR READER. If you're reading this, the joke's on me. You're clearly still brain-functional. Congratulations!

But humor me for a moment. What if your brain really did go offline? What would you miss most?

Your memories? Your ability to speak? Your sense of self?

Here's a mind-bender: You wouldn't miss anything. Because without your brain, there wouldn't be a "you" to do the missing.

Your brain isn't just a tool you use. It is you. Every thought, every feeling, every quirk that makes you uniquely you - it's all in that 3-pound blob of jelly between your ears.

So maybe the real question is: who's in charge here? You, or your brain?

It's a trick question.

You ARE your brain. But also… you're so much more.

You're the stories you tell yourself. You're the habits you've formed. You're the people you love and who love you back.

You're a walking, talking, miracle of nature - 86 billion neurons working in harmony to create the experience of being you.

And the coolest part? You can change. You can rewrite your stories. You can form new habits. You can forge new connections - neural and social.

So, DEAR READER, let's put this power to use. Here are three "brain hacks" to tap into your neural plasticity:

1. **The 2-Minute Rule: When a task seems daunting, commit to just 2 minutes. Your brain, wired to finish what it starts, will often keep going. Writing a book becomes "write one sentence." Cleaning the house becomes "pick up one item." Small wins snowball into big changes.**
2. **Sensation Swapping: Deliberately mix up your senses. Eat with your eyes closed. Listen to music while focusing on what you feel rather than hear. This forces your brain to create new neural pathways, enhancing creativity and cognitive flexibility.**
3. **The Feynman Technique: To learn anything, explain it to a 12-year-old (real or imaginary). This forces your brain to translate complex ideas into simple terms, solidifying your understanding and highlighting knowledge gaps.**

Remember: You're not just a brain. You're a brain-powered possibility machine.

Now, if you'll excuse me, I need to go reboot my own brain. I hear a 20-minute power nap works wonders.

Stay miraculous,

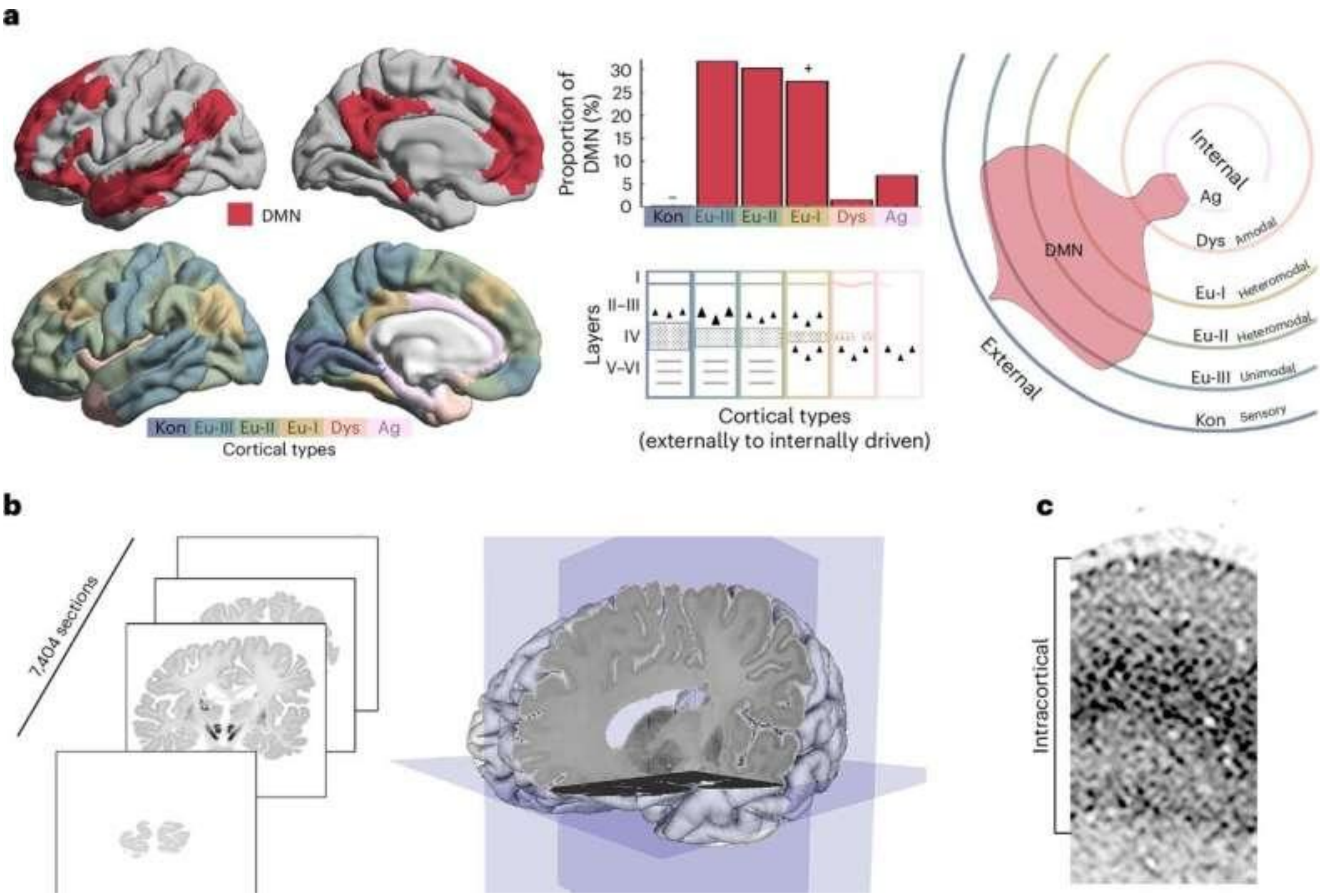
Lee Anderson
Founder, NeuroLaunch.com

P.S. This email will self-destruct in 5… 4… 3…

Just kidding. But your brain is constantly destroying and recreating memories as we speak. Why not use this to your advantage? Each night, mentally review one thing you want to remember. Your brain will strengthen that neural pathway, making the memory more resilient. Sweet dreams!

Mapping the human brain's default mode network: Anatomical study suggests it has widespread influence

by Ingrid Fadelli , Medical Xpress



Cytoarchitectural heterogeneity of the DMN. Credit: *Nature Neuroscience* (2025). DOI: 10.1038/s41593-024-01868-0

The default mode network (DMN) is a set of interconnected brain regions known to be most active when humans are awake but not engaged in physical activities, such as relaxing, resting or daydreaming. This brain network has been found to support a variety of mental functions, including introspection, memories of past experiences and the ability to understand others (i.e., social cognitions).

The DMN includes four main brain regions: the medial prefrontal cortex (mPFC), the posterior cingulate cortex (PCC), the angular gyrus and the hippocampus. While several studies have explored the function of this network, its anatomical structure and contribution to information processing are not fully understood.

Researchers at McGill University, Forschungszentrum Jülich and other institutes recently carried out a study aimed at better understanding the anatomy of the DMN, specifically examining the organization of neurons in the tissue of its connected brain regions, which is known as cytoarchitecture. Their findings, published in *Nature Neuroscience*, offer new indications that the DMN has a widespread influence on the human brain and its associated cognitive (i.e., mental) functions.

"The default mode network (DMN) is implicated in many aspects of complex thought and behavior," Casey Paquola, Margaret Garber and their colleagues wrote in their paper. "We leverage postmortem histology and in vivo neuroimaging to characterize the anatomy of the DMN to better understand its role in information processing and cortical communication."

To closely examine the anatomy of the DMN, Paquola, Garber and their colleagues used two main experimental approaches, known as post-mortem histology and in vivo neuroimaging. The first of these approaches entails the microscopic examination of brain tissue preserved from deceased patients, while the second involves scanning the brains of living individuals.

"Our results show that the DMN is cytoarchitecturally heterogenous, containing cytoarchitectural types that are variably specialized for unimodal, heteromodal and memory-related processing," wrote Paquola, Garber and their colleagues. "Studying diffusion-based structural connectivity in combination with cytoarchitecture, we found the DMN contains regions receptive to sensory cortex input and a core relatively insulated from environmental input."

By mapping white matter pathways in the human brain, the researchers learned more about the organization and structure of the DMN. Specifically, they found that this network is made up of brain regions that receive sensory inputs and a "core" that is relatively "shielded" from the outside world (i.e., does not receive many external inputs).

"Finally, analysis of signal flow with effective connectivity models showed that the DMN is unique among cortical networks in balancing its output across the levels of sensory hierarchies," wrote Paquola, Garber and their colleagues. "Together, our study establishes an anatomical foundation from which accounts of the broad role the DMN plays in human brain function and cognition can be developed."

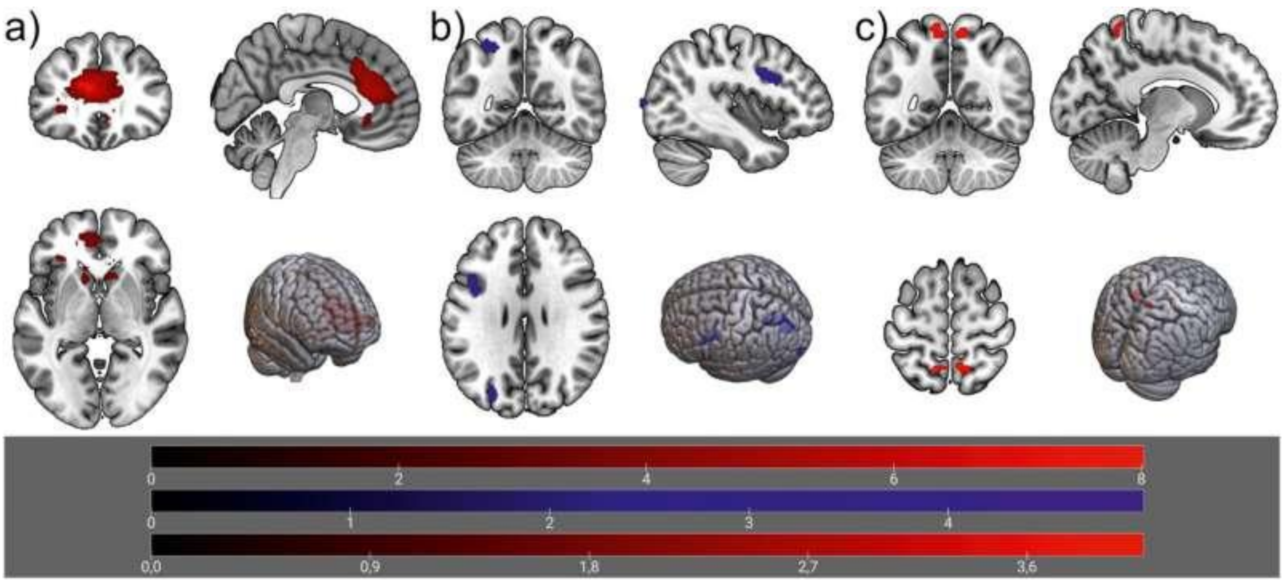
This recent study by Paquola, Garber and their colleagues could significantly advance the present understanding of the DMN, offering valuable insight about its cytoarchitecture, the connections between its underlying brain structures, and how it contributes to mental functions. The researchers' findings and the anatomical framework they introduced could inspire further research into this crucial brain network, which could shed new light on its contribution to healthy cognitive function, and specific mental health disorders.

More information: Casey Paquola et al, The architecture of the human default mode network explored through cytoarchitecture, wiring and signal flow, *Nature Neuroscience* (2025). DOI: 10.1038/s41593-024-01868-0.
Journal information: Nature Neuroscience

MARCH 4, 2025

Scientists observe that smartphone restriction for three days can alter brain activity

by Sanjukta Mondal , Medical Xpress



CR-related brain activity over time. a) PHONE > NEU T2 – T1 (red) at $p < 0.001$, $k = 7$. b) ON > OFF T1 – T2 (blue) at $p < 0.001$, $k = 9$. c) Time-group interaction T2 > T1 and ESU > non-ESU of ON > OFF (red) at $p < 0.001$, $k = 9$. Color bars depict T-values of the respective contrasts, top: a), middle: b), bottom c). This figure was created using GIMP and MRIcroGL (https://www.nitrc.org/projects/mricrogl; last visited 01/21/2024).
Credit: *Computers in Human Behavior* (2025). DOI: 10.1016/j.chb.2025.108610

A smartphone's glow is often the first and last thing we see as we wake up in the morning and go to sleep at the end of the day. It is increasingly becoming an extension of our body that we struggle to part with. In a recent study in *Computers in Human Behavior*, scientists observed that staying away from smartphones can even change one's brain chemistry.

The researchers recruited young adults for a 72-hour smartphone restriction diet where they were asked to limit smartphone use to essential tasks such as work, daily activities, and communication with their family or significant others.

During these three days, the researchers conducted psychological tests and did brain scans using functional magnetic resonance imaging (fMRI) to examine the effects of restricting phone usage. Brain scans showed significant activity shifts in reward and craving regions of the brain, resembling patterns seen in substance or alcohol addiction.

There is an ongoing debate about the term "smartphone addiction" (SPA) making an appearance in many psychological tests, as experts believe that this term might create an inaccurate image of the complex emotional, mental and social aspects associated with smartphone overuse. Nevertheless, neuroscience has seen a growing focus on excessive smartphone use (ESU) due to its association with negative physical and mental health effects, and its links to addictive behaviors.

For this study, 25 young adults aged 18 to 30 who regularly used smartphones were selected. Before the 72-hour restriction period, participants were screened for the severity of physical, psychological, and social issues related to smartphone use and computer gaming, as well as to ensure they did not have any existing mental health conditions.

To assess their mood, smartphone habits, and cravings, participants completed two questionnaires before their first brain scan. They were then instructed to limit phone use for the next 72 hours.

After the three-day restriction period, participants underwent fMRI scans while being shown different sets of images: neutral scenes (such as landscapes and boats), smartphones turned on, and smartphones turned off.

The scans revealed that limiting smartphones led to brain activity changes in areas associated with dopamine and serotonin—neurotransmitters that regulate mood, emotions and also addiction.

The researchers noted that smartphone restriction can resemble withdrawal from addictive substances or even food cravings in some ways, which was noticeable in both heavy (ESU) and regular smartphone (non-ESU) participants.

As technology advances, recognizing how our smartphone usage habits affect our brains is crucial for building healthier digital routines.

More information: Mike M. Schmitgen et al, Effects of smartphone restriction on cue-related neural activity, *Computers in Human Behavior* (2025). DOI: 10.1016/j.chb.2025.108610
Journal information: Computers in Human Behavior

MARCH 7, 2025

How the brain turns sound into conversation: Study uncovers the neural pathways of communication

by Hebrew University of Jerusalem

Credit: Unsplash/CC0 Public Domain

A new study has uncovered how the brain seamlessly transforms sounds, speech patterns, and words into the flow of everyday conversations. Using advanced technology to analyze over 100 hours of brain activity during real-life discussions, researchers revealed the intricate pathways that allow us to effortlessly speak and understand.

These insights not only deepen our understanding of human connection but also pave the way for transformative advancements in speech technology and communication tools.

The study, led by Dr. Ariel Goldstein, from the Department of Cognitive and Brain Sciences and the Business School at the Hebrew University of Jerusalem, Google Research, in collaboration with the Hasson Lab at the Neuroscience Institute at Princeton University, Dr. Flinker and Dr. Devinsky, from the NYU Langone Comprehensive Epilepsy Center, has developed a unified computational framework to explore the neural basis of human conversations.

This research bridges acoustic, speech, and word-level linguistic structures, offering unprecedented insights into how the brain processes everyday speech in real-world settings.

The study, published in *Nature Human Behaviour,* recorded brain activity over 100 hours of natural, open-ended conversations using a technique called electrocorticography (ECoG).

To analyze this data, the team used a speech-to-text model called Whisper, which helps break down language into three levels: simple sounds, speech patterns, and the meaning of words. These layers were then compared to brain activity using advanced computer models.

The results showed that the framework could predict brain activity with great accuracy. Even when applied to conversations that were not part of the original data, the model correctly matched different parts of the brain to specific language functions. For example, regions involved in hearing and speaking aligned with sound and speech patterns, while areas involved in higher-level understanding aligned with the meanings of words.

The study also found that the brain processes language in a sequence. Before we speak, our brain moves from thinking about words to forming sounds, while after we listen, it works backwards to make sense of what was said. The framework used in this study was more effective than older methods at capturing these complex processes.

"Our findings help us understand how the brain processes conversations in real-life settings," said Dr. Goldstein. "By connecting different layers of language, we're uncovering the mechanics behind something we all do naturally—talking and understanding each other."

This research has potential practical applications, from improving speech recognition technology to developing better tools for people with communication challenges. It also offers new insights into how the brain makes conversation feel so effortless, whether it's chatting with a friend or engaging in a debate.

The study marks an important step toward building more advanced tools to study how the brain handles language in real-world situations.

More information: A unified acoustic-to-speech-to-language embedding space captures the neural basis of natural language processing in everyday conversations, *Nature Human Behaviour* (2025). DOI: 10.1038/s41562-025-02105-9
Journal information: Nature Human Behaviour
Provided by Hebrew University of Jerusalem

Explore further

A little-known brain region at the heart of communication

Published March 08, 2025

Nature Communications
When we speak, emphasizing a word or raising our voice on a syllable can radically change the meaning of a sentence.

For example, saying "Did you do it?" with a rising intonation suggests a question, while "You did it." with a falling tone implies a statement. Similarly, stressing a word gives it particular weight and thus intention, as in the case of saying "it was [YOU] who did it": this points an accusatory finger at our interlocutor. A recent study reveals that our brain processes these melodic nuances much earlier than previously thought, thanks to a little-known brain region.

This discovery, published in *Nature Communications*, improves our understanding of language perception. By analyzing the brain activity of epileptic patients, researchers have identified the key role of Heschl's gyrus, in the cerebral cortex, in interpreting variations in voice pitch, called prosody. These variations, often imperceptible, are nevertheless essential for grasping the intention and emotion behind words.

Heschl's gyrus: much more than a simple sound processor

Heschl's gyrus, a region of the auditory cortex, was until now considered a simple sound detector. Researchers have discovered that it also plays a role in transforming tone variations into meaningful linguistic information. Thus, this region does not merely process raw sounds, but categorizes pitch accents to extract meaning.

This ability to interpret prosody is unique to humans. Experiments conducted on macaques have shown that although these animals perceive the same acoustic variations, they do not process them as linguistic units. This suggests that this skill is the result of our notion of language.

Using intracranial recordings in epileptic patients, researchers observed that Heschl's gyrus encodes voice pitch variations into distinct linguistic units. These units, called pitch accents, are processed separately from the sounds that make up words, revealing an unsuspected specialization of this brain region.

Practical implications for health and technology

These findings could improve the management of language disorders, such as autism or stroke sequelae. By better understanding how the brain processes prosody, therapies could become more targeted and effective. For example, specific exercises could help patients better interpret intonations, thereby improving their daily communication.

Moreover, this discovery could enhance voice recognition systems. Currently, voice assistants struggle to interpret emotional nuances or intentions behind words. By integrating these mechanisms, technologies could become more intuitive and human-like, enabling more natural interaction between humans and machines.

This breakthrough opens up new perspectives for neuroscience research. By studying the role of Heschl's gyrus in more detail, scientists could discover new avenues for treating other neurological disorders related to auditory perception or language. These findings could also shed light on the brain mechanisms involved in language learning.

To go further: How does the brain process sounds?

The brain breaks down sounds into several stages. First, primary auditory regions, such as Heschl's gyrus, process basic acoustic characteristics, such as pitch, intensity, and timbre. This information is then transmitted to more specialized areas for further analysis.

Next, regions such as the superior temporal gyrus intervene to interpret these sounds in a linguistic context. They allow for the distinction of phonemes, words, and sentences.

This information is then relayed to associative areas that link it to memory, emotions, and other cognitive functions. This explains why a particular intonation can evoke memories or elicit emotional reactions.

Pupils reveal our brain activity 👁️

Published by Cédric, March 10, 2025 at 02:00 AM

Article author: Cédric DEPOND

Source: Nature Communications

The pupils, those small black circles at the center of our eyes, could well become a key to understanding sleep. A team of researchers has discovered that their size constantly varies during sleep, reflecting brain activity that is much more intense than previously imagined.

This study, conducted by scientists at ETH Zurich, reveals that the brain remains partially awake even during rest. The pupils, by changing size, betray these fluctuations in brain activation, thus offering a new tool to explore the mechanisms of sleep.

Pupils, witnesses of brain activity

The researchers have developed a novel technique to observe pupils during sleep. Using a device that keeps the eyes open, they were able to track pupillary variations over several hours. These measurements revealed that pupils react to different stages of sleep, such as slow waves or sleep spindles.

These fluctuations reflect the brain's state of wakefulness, challenging the idea of a completely inactive brain during rest. The researchers also observed that the brain reacts differently to sound stimuli depending on its level of activation, which is reflected in changes in pupil size.

The results suggest that pupils act as precise indicators of brain activity. This discovery opens the way to a better understanding of the mechanisms of sleep and their links with essential functions such as memory or the regulation of wakefulness.

Promising implications for sleep medicine

These findings could transform the diagnosis and treatment of sleep disorders. By analyzing pupillary dynamics, researchers hope to better understand pathologies such as insomnia or post-traumatic stress. These variations could also serve as markers to monitor wakefulness in comatose patients.

In the long term, this technology could be used outside specialized laboratories, for example in hospitals. It would improve the monitoring of patients with sleep disorders or consciousness disorders, offering more precise and less invasive diagnostic tools.

Pupils, as windows to the brain, open new perspectives for research and medicine. These advances could also contribute to the study of neurodegenerative diseases, such as Alzheimer's, by providing clues about dysfunctions in brain activation.

To go further: why do pupils change size?

The size of the pupils is regulated by muscles in the iris, which contract or dilate in response to light and brain activity. These changes are controlled by the autonomic nervous system, which manages the body's involuntary functions. During sleep, pupillary variations reflect the brain's state of activation, thus providing a valuable indicator of neural activity.

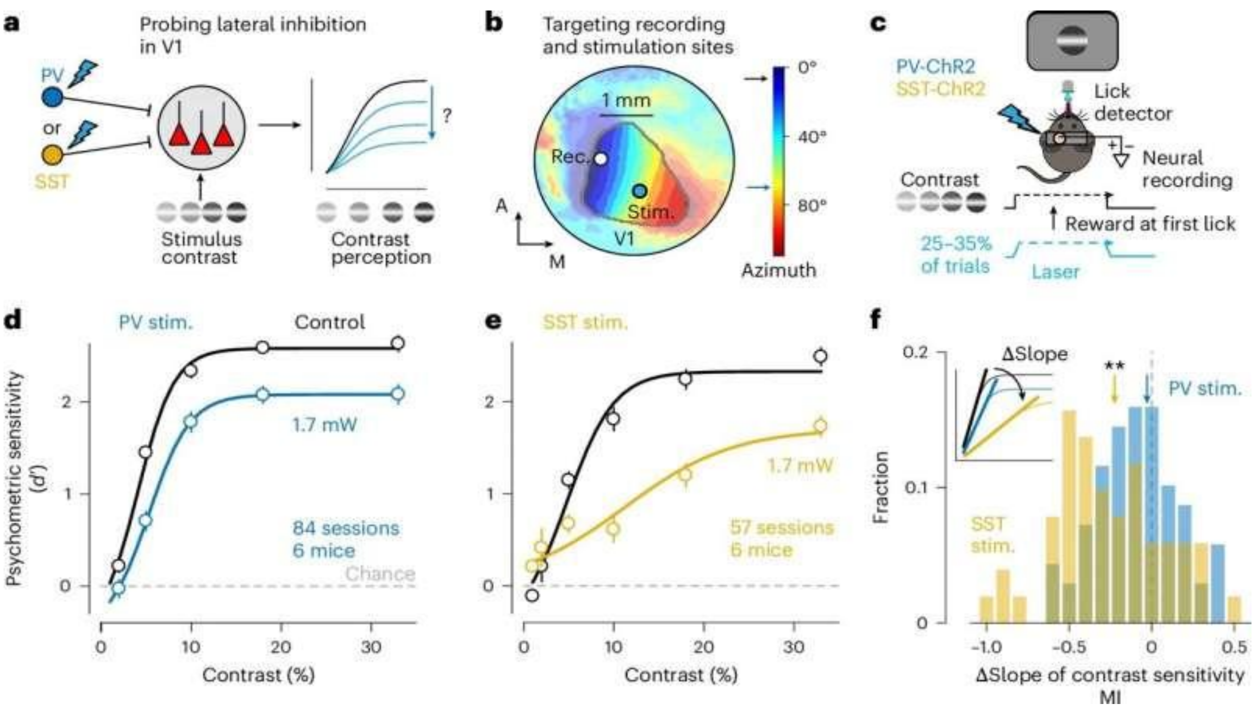
Pupils also react to internal stimuli, such as emotions or stress levels. For example, in cases of surprise or fear, they dilate rapidly. These reactions are linked to the activity of deep brain regions, such as the locus coeruleus, which plays a key role in modulating wakefulness and attention.

During sleep, pupillary fluctuations are correlated with specific phases, such as sleep spindles or slow waves. These variations allow researchers to study the mechanisms of sleep regulation and better understand how the brain transitions from a state of rest to a state of partial wakefulness.

Finally, changes in pupil size could serve as markers to diagnose sleep disorders or dysfunctions in brain activation. This non-invasive approach opens new perspectives for neuroscience research and sleep medicine.

Sharper images: How the brain filters out the noise

by Jerry Grillo, Georgia Institute of Technology



SST lateral inhibition controls the slope of psychometric contrast sensitivity. Credit: *Nature Neuroscience* (2025). DOI: 10.1038/s41593-025-01888-4

A multidisciplinary team of researchers at Georgia Tech has discovered how lateral inhibition helps our brains process visual information, and it could expand our knowledge of sensory perception, leading to applications in neuro-medicine and artificial intelligence.

Lateral inhibition is when certain neurons suppress the activity of their neighboring neurons. Imagine an artist drawing, darkening the lines around the contours, highlighting the boundaries between objects and space, or objects and other objects. Comparably, in the visual system, lateral inhibition sharpens the contrast between different visual stimuli.

"This research is really getting at how our visual system not only highlights important things, but also actively suppresses irrelevant information in the background," said lead researcher Bilal Haider, associate professor in the Wallace H. Coulter Department of Biomedical Engineering. "That ability to filter out distractions is crucial."

Understanding how these inhibitory mechanisms work could provide insights into why people have trouble filtering out distractions or focusing on what's important in conditions like autism or ADHD.

"Our findings may also influence how we design artificial intelligence and neural networks," said Haider, whose team published its work this month in *Nature Neuroscience*. "Current AI systems treat all the computing units the same, but the brain has figured out how to assign specialized computing roles."

Joseph Del Rosario, a former graduate student in the Haider lab, was the lead author. Another key contributor was Hannah Choi, assistant professor in the School of Mathematics, and her Research Group in Mathematical Neuroscience. Their team built computational models to test the biological findings.

"Collaborating with mathematicians to really understand the computational principles underlying these inhibitory processes is a great example of how neuroscience can inform fields like AI," Haider said.

Fine-tuning perception

The study focused on two types of inhibitory neurons in the visual cortex: parvalbumin (PV) neurons and somatostatin (SST) neurons. The researchers used optogenetics—a technique that uses light to control cell activity—to activate PV and SST neurons in the visual cortex of mice. What they observed was striking.

"What's fascinating is that different types of inhibitory neurons seem to be doing distinct mathematical computations to achieve this suppression of the visual field," Haider said. "It's not a one-size-fits-all process."

When the team activated PV neurons, visual contrast sensitivity was evenly reduced, like lowering the brightness on a computer monitor. Activation of SST neurons resulted in a more nuanced change, altering the slope of the contrast sensitivity curve, which is a graph showing how well your visual system can detect contrast.

"Basically, SST neurons fine-tune our perception of contrast more strongly by reducing extra, unnecessary signals," Haider said. "That's lateral inhibition at work. These inhibitory neurons play a major role in our perception. The brain has evolved this precise wiring and division of labor among different neuron types to act as the brakes in the visual system, just as important as the accelerator."

The impact of lateral inhibition goes beyond the visual system. Similar processes may also be at work in other senses, like hearing and touch. As scientists develop a better understanding of how the brain filters sensory information, they may discover new ways to enhance or restore our overall sensory experience.

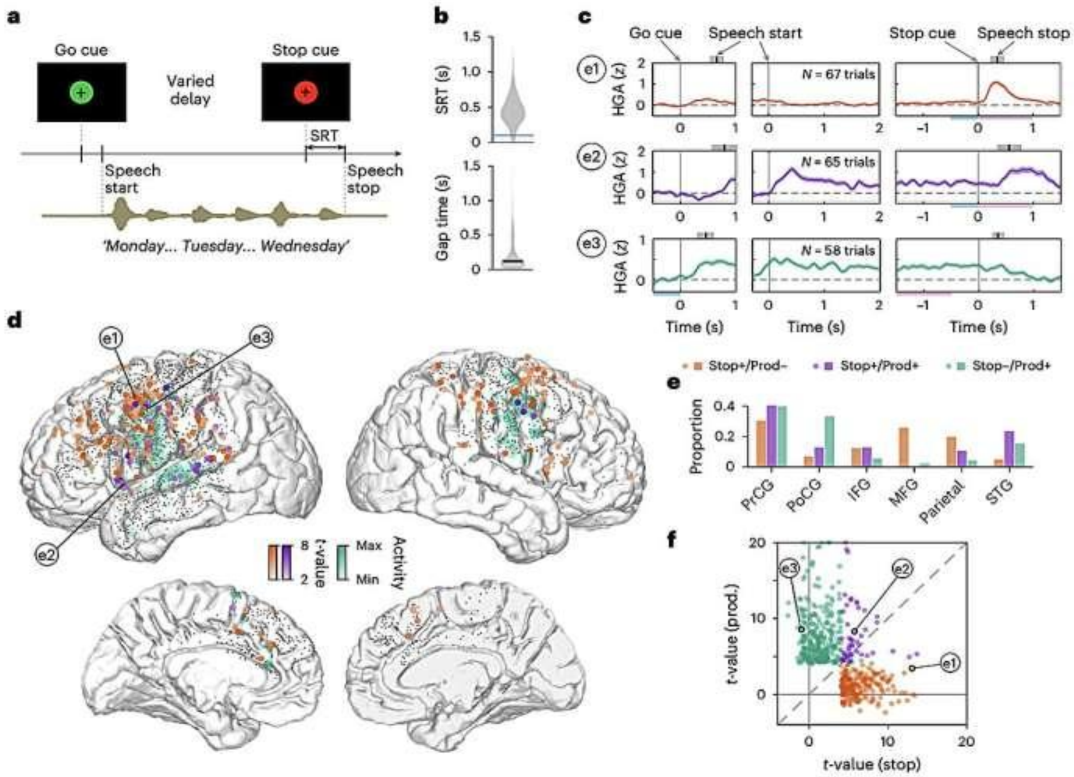
Haider first conceived the idea for this work 10 years ago when he was a postdoc. He believes the research could possibly result in new treatments for visual disorders, and lead to more flexible AI.

More information: Joseph Del Rosario et al, Lateral inhibition in V1 controls neural and perceptual contrast sensitivity, *Nature Neuroscience* (2025). DOI: 10.1038/s41593-025-01888-4
Journal information: Nature Neuroscience
Provided by Georgia Institute of Technology

MARCH 12, 2025

A premotor cortical network in the brain allows people to voluntarily stop speaking, study suggests

by Ingrid Fadelli , Medical Xpress



Premotor neural activation during speech stopping. Credit: *Nature Human Behaviour* (2025). DOI: 10.1038/s41562-025-02118-4

Speech is a unique human ability that is known to be supported by various motor and cognitive processes. When humans start speaking, they can decide to cease at any point; for instance, if they are interrupted by something happening or by another person speaking to them.

The ability to voluntarily stop speaking plays a central role in social interactions, as it allows people to engage in conversations with others while adaptively responding to social cues, environmental stimuli or interruptions. While many past studies explored the neural and cognitive underpinnings of speech itself, the brain processes associated with speech inhibition remain poorly understood.

Researchers at the University of California San Francisco recently set out to better understand how the human brain controls the ceasing of speech using tools to record neurophysiological signals. Their paper, published in *Nature Human Behaviour*, unveils a previously unknown premotor cortical network that could support voluntary speech inhibition.

"The cognitive and neural mechanisms of speech inhibition are not well understood," wrote Lingyun Zhao, Alexander B. Silva and their colleagues in their paper. "We have recorded direct high-density cortical activity while participants engaged in continuous speech production and were visually cued to stop speaking."

To investigate the neural underpinnings of voluntary speech cessation, Zhao, Silva and their colleagues used a neurophysiological recording technique known as high-density electrocorticography (ECoG). This technique allows researchers to monitor the electrical activity originating from the surface of the brain.

They recruited 13 patients diagnosed with treatment-resistant epilepsy who had electrodes implanted on their brains' surfaces to better understand the brain regions that contribute to their epileptic seizures. These patients were asked to complete a speech-stopping task, which asked them to follow instructions on when to start and stop speaking, while their neural activity was recorded.

"Neural recordings revealed distinct activity in the premotor frontal cortex correlated with stopping speech," wrote the researchers. "This activity was found in largely separate cortical sites from regions encoding vocal tract articulatory movements. Moreover, this activity primarily occurred with abrupt stopping in the middle of an utterance, rather than naturally completing a phrase."

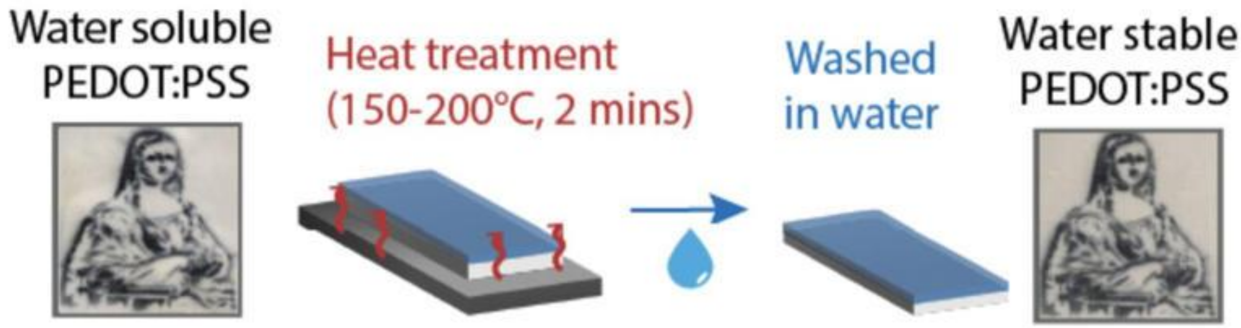
The findings gathered by this team of researchers hint at the existence of a specialized brain mechanism that supports the voluntary control of speech. Zhao, Silva and their colleagues conducted further tests aimed at validating the existence of this mechanism by stimulating specific parts of the premotor frontal cortex.

"Electrocortical stimulation at many premotor sites with inhibitory stop activity caused involuntary speech arrest, which contradicts previous clinical interpretations of this effect as evidence for critical centers of speech production," wrote the team. "Together, these results suggest a previously unknown premotor cortical network that supports the inhibitory control of speech, providing implications for understanding both natural and altered speech production."

Overall, the results of this study suggest that the human ability to voluntarily stop speech is supported by a particular inhibitory control neural network that had not been uncovered before. Future studies could help to further elucidate the functions and contributions of the newly identified premotor cortical network, which could in turn help to better understand some disorders linked to an impaired ability to voluntarily control speech.

More information: Lingyun Zhao et al, Inhibitory control of speech production in the human premotor frontal cortex, *Nature Human Behaviour* (2025). DOI: 10.1038/s41562-025-02118-4
Journal information: Nature Human Behaviour

Heat-based stabilization of a conductive polymer simplifies bioelectronics fabrication



Overview of the heat treatment process, demonstrated with a screen printed PEDOT:PSS pattern on fabric that remains stable after washing in detergent. Credit: Advanced Materials (2025). DOI: 10.1002/adma.202415827

Recent advances in the field of materials science have opened new possibilities for the fabrication of bioelectronics, devices designed to be worn or implanted in the human body. Bioelectronics can help to track or support the function of organs, tissues and cells, which can contribute to the prevention and treatment of various diseases.

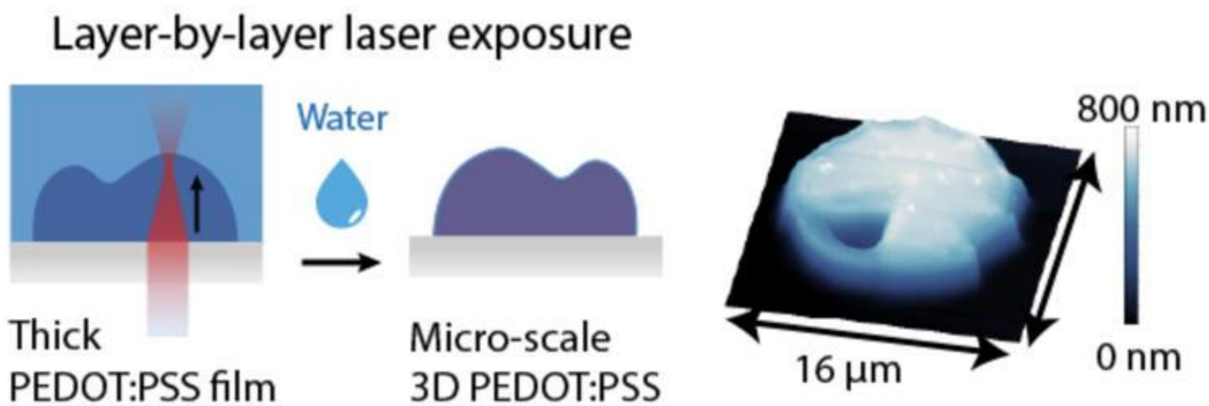
A promising material for the fabrication of bioelectronics is PEDOT:PSS, a polymer known for its high electrical conductivity, flexibility and compatibility with biological tissues. Despite its advantageous properties, PEDOT:PSS is known to gradually dissolve in biological fluids, a limitation that has so far been counteracted using chemical compounds and processes.

Researchers at Stanford University, the University of Cambridge and Rice University recently uncovered an easier and potentially safer strategy to stabilize this bio-compatible polymer using heat. Their proposed thermal treatment, outlined in the journal *Advanced Materials*, was found to make PEDOT:PSS films stable in water without the need for any chemical additives.

"This work started out from a serendipitous discovery during the course of my previous research, where I was using the responsive polymer, PEDOT:PSS to make shape-changing photonic devices," Siddharth Doshi, co-first author of the paper, told Tech Xplore.

"I noticed that films of PEDOT:PSS that I'd accidentally baked at higher than usual temperatures didn't dissolve in water. This was a huge surprise, as PEDOT:PSS is a widely studied conductive polymer, and to get around the fact that it delaminates in water, hundreds of bioelectronics papers use chemical cross-linkers to stabilize their devices."

After making this surprising observation as part of their earlier research, Doshi and his colleagues set out to explore the possibility that heating up PEDOT:PSS films could also stabilize them in fluids. In addition, they wished to determine what exactly happened when the films were heated above certain temperatures, how this heating process affected their properties and whether a heat-based approach could replace existing chemical stabilization processes.



Layer-by-layer exposure to a focused femtosecond laser beam allows for microscale-3D printing of unmodified PEDOT:PSS. Credit: Advanced Materials (2025). DOI: 10.1002/adma.202415827

"The key advantage of our approach is its simplicity—you can simply heat up films of commercial, unmodified PEDOT:PSS on a hot-plate between 150°C and 200°C for 2 mins, and it no longer dissolves in water," explained Doshi. "It works on different substrates, including stretchable plastics and even different fabrics, and avoids many of the complications of chemical crosslinkers, which affect the conductivity and reliability of the films."

The heat treatment devised by the researchers could also enable the direct patterning of PEDOT:PSS simply by applying heat to specific sites on the films and thus removing the need for complex lithography techniques. As part of their study, Doshi and his colleagues also demonstrated the 3D printing of PEDOT:PSS at the micro-scale, using a focused femtosecond laser beam.

"The PEDOT:PSS absorbs strongly at the near-infrared laser wavelength we used, which causes local heating," said Doshi. "Through layer-by-layer scanning of a focused laser spot, we could locally stabilize 3D patterns within the film which remain even after the unexposed parts of the film are washed away in water. As a nice additional benefit, this gives us an environmentally friendly way to pattern this material, using only water for processing instead of other toxic solvents."

The initial tests run by the researchers yielded very promising results. Ultimately, their heat-based approach was found to make PEDOT:PSS films stable in water, while also improving their performance.

"Heat-treated bioelectronic devices such as transistors, spinal cord stimulators and electrocorticography (ECoG) arrays were easier to fabricate, more reliable, and equally high performing. And they proved to be robust in chronic in vivo experiments, maintaining stability for over 20 days post-implantation," said Margaux Forner, Ph.D. student from the University of Cambridge and co-first author on the paper.

"Notably, the film maintained excellent electrical performance when stretched, highlighting its potential for resilient bioelectronic devices both inside and outside the body."

"Our characterization suggests that heat-treatment drives phase separation of PEDOT and PSS-rich regions, helping stabilize the polymer blend by creating a network of a water-insoluble, PEDOT-rich phase," added Scott Keene, Assistant Professor at Rice University and the senior author of the paper. "In addition to making the polymer water-stable, we found that phase separation improves both the conductivity and capacitance of our films, two critical parameters for bioelectronic devices."

In addition, the simple heat-based treatment introduced by Doshi and his colleagues could be easily integrated with existing manufacturing processes. In the future, it could thus simplify the development of various PEDOT:PSS-based devices, including bioelectronics, as well as wearable electronics and electronic skins.

"We are also really excited about the ability to 3D-print the polymers at the microscale," said Doshi. "This has been a major goal for the community, as writing this functional material in 3D could let you interface with the 3D world of biology.

Typically, this is done by combining PEDOT:PSS with different photo-sensitive binders or resins; however, these additions affect the properties of the material or are challenging to scale down to micron-length scales."

The researchers have successfully used their heat-based approach to create complex 3D structures, including blocks, textured surfaces and sculptural test-pieces with curves, bevels and recesses, made of PEDOT:PSS. They achieved this using femtosecond laser patterning, but it could eventually also be attained using other laser-based methods.

The researchers hope that other materials scientists and engineers will start experimenting with their thermal treatment and using it to stabilize PEDOT:PSS films without relying on chemical processes. In the future, their newly introduced approach could facilitate the use of these films for the development of implantable devices and other devices that are meant to be resistant to water or other fluids.

"One direction for future research will be to explore new ways to interface with the 3D world of biology through functional cell-interfaces," said Doshi. "We are also interested in going back to our original motivation of exploring new ways of fabricating PEDOT:PSS, which is in making switchable 3D photonic devices that use the electro-optic tunability of PEDOT:PSS to dynamically change their optical properties.

"There is a lot of interest in the field of micro and nano-optics for devices that change their functionality on demand, and 3D devices could have a lot of advantages over 2D devices that have been most widely explored to date."

In their next studies, Doshi and his colleagues also plan to further investigate the fundamental mechanisms underpinning the stabilization of PEDOT:PSS when it is heated above 150°C for over two minutes. To do this, they will employ advanced imaging and material characterization techniques.

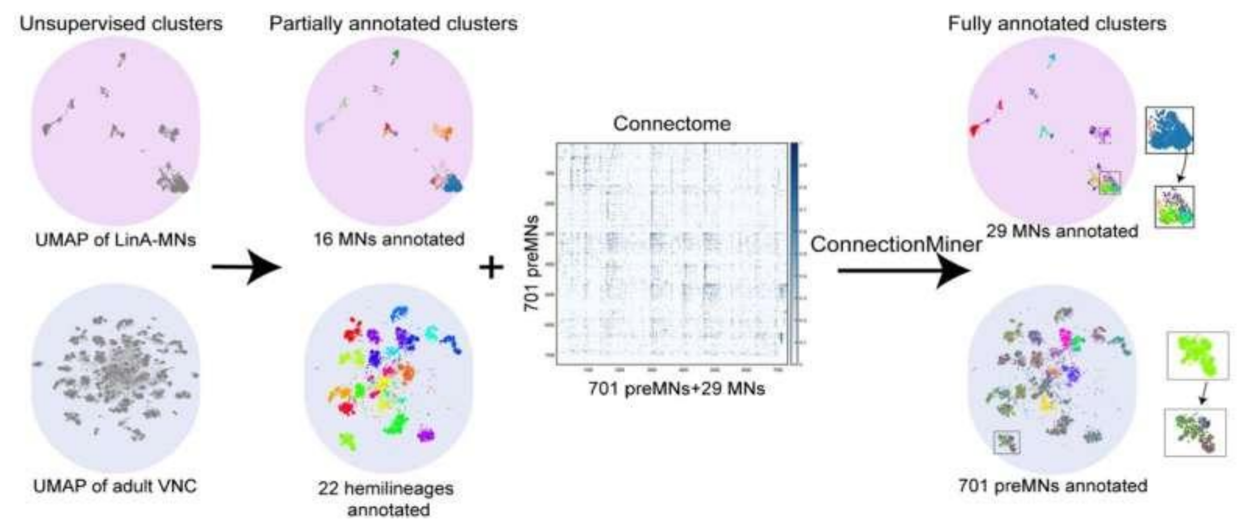
"Techniques like in-situ transmission electron microscopy or in-situ X-ray diffraction could let us visualize what is exactly happening to the PEDOT and PSS chains and the overall microstructure of the material in real-time," added Doshi.

More information: Doshi et al, Thermal Processing Creates Water-Stable PEDOT:PSS Films for Bioelectronics, *Advanced Materials* (2025). DOI: 10.1002/adma.202415827

MARCH 13, 2025

New research uses AI to unravel the complex neuronal wiring of the motor system

by NYU Tandon School of Engineering



Overview of ConnectionMiner. Credit: *Neuroscience* (2025). DOI: 10.1101/2025.03.04.640006

The nervous system is a marvel of biological engineering, composed of intricate networks that control every aspect of an animal's movement and behavior. A fundamental question in neuroscience is how these vast, complex circuits are assembled during development.

A recent study by a group of researchers including Erdem Varol, Assistant Professor of Computer Science and Engineering and a member of the Visualization, Imaging and Data Analysis Center, has provided new insights into this problem by studying how the neurons responsible for leg movement in fruit flies (Drosophila melanogaster) establish their connections.

The researchers developed ConnectionMiner, a novel computational tool that integrates gene expression data with electron microscopy-derived connectomes. This tool enabled them to infer neuronal identities and predict synaptic connectivity with remarkable accuracy. Their findings, posted to the *bioRxiv* preprint server, offer a blueprint for understanding how neurons wire themselves into functional circuits.

Neurons form connections based on genetic and molecular cues, but identifying the precise mechanisms behind this process has been difficult. In the fruit fly, roughly 69 motor neurons (MNs) in each leg are responsible for controlling movement. These neurons receive input from more than 1,500 premotor neurons (preMNs) through over 200,000 synapses. The challenge lies in understanding how each MN finds the right preMN partners and how these connections are established at the molecular level.

By applying single-cell RNA sequencing (scRNAseq) at multiple developmental stages, the researchers tracked how different gene families, particularly transcription factors (TFs) and cell adhesion molecules (CAMs), shape the unique identities of MNs. They discovered that these molecular signals not only define neuronal types but also correlate with the strength of their synaptic connections.

Traditional methods of studying neuronal circuits rely on either gene expression data (which tells us what molecules neurons produce) or connectomics (which maps how neurons are wired together). However, integrating these two datasets has been a major challenge. ConnectionMiner bridges this gap by using machine learning to refine ambiguous neuronal annotations, effectively reconstructing the genetic and synaptic landscape of the nervous system.

The researchers tested their tool on the Drosophila leg motor system, identifying combinatorial gene signatures that likely orchestrate the assembly of circuits from preMNs to MNs and ultimately to muscles. By leveraging both transcriptomic (gene expression) and connectomic (wiring) data, ConnectionMiner successfully resolved previously uncharacterized neuronal identities and predicted the molecular interactions driving connectivity.

By mapping these relationships, ConnectionMiner provides a predictive framework for understanding how the nervous system assembles itself.

"The nervous system is one of the most complex networks that we know of, and deciphering its molecular building blocks is key to understanding much about our health, our behavior and our lives in general," says Varol. "Tools like ConnectionMiner are a major stepping stone towards unlocking the brain's molecular blueprint—enabling us to identify the genes that build neural circuits, revolutionize the diagnosis and treatment of neurological disorders, and fundamentally enhance our understanding of how brain wiring drives behavior."

This research has far-reaching implications. Understanding the molecular rules that govern neural connectivity in fruit flies could inform studies of more complex nervous systems, including our own. The principles uncovered here might help explain how neural circuits form during development, how they recover from injury, and even how neurodevelopmental disorders arise when connectivity goes awry.

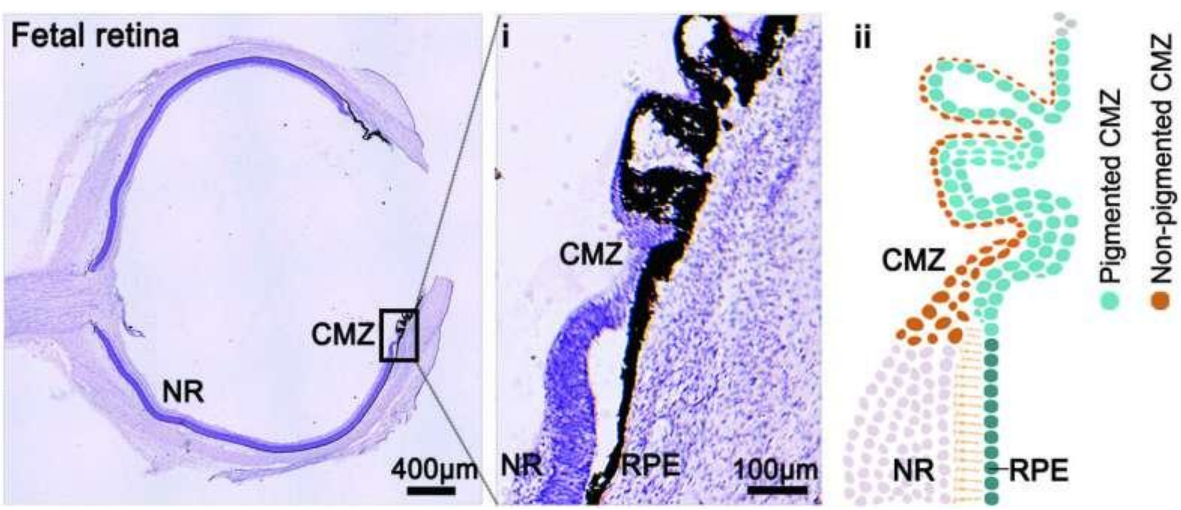
Furthermore, computational tools like ConnectionMiner represent a paradigm shift in neuroscience. By integrating artificial intelligence with biological data, researchers can now tackle questions that were previously too complex to analyze. The approach outlined in this study could be applied to other model organisms, potentially unlocking new insights into brain development, neural repair, and artificial intelligence itself.

More information: Himanshu Pawankumar Gupta et al, Decoding neuronal wiring by joint inference of cell identity and synaptic connectivity, *bioRxiv* (2025). DOI: 10.1101/2025.03.04.640006
Journal information: Neuroscience , bioRxiv
Provided by NYU Tandon School of Engineering

MARCH 28, 2025

Human retinal stem-like cells with potential to repair vision loss discovered

by Justin Jackson , Medical Xpress



H&E staining of an 18-week human fetal retina, showing the spatial distribution and differentiation potential of human retinal stem cells in the ciliary marginal zone. Credit: Jianzhong Su, State Key Laboratory of Eye Health, Eye Hospital, Wenzhou Medical University

Wenzhou Medical University and collaborating institutions have identified a population of human neural retinal stem-like cells able to regenerate retinal tissue and support visual recovery.

Vision loss caused by retinal degeneration affects millions worldwide. Conditions such as retinitis pigmentosa and age-related macular degeneration involve the irreversible loss of light-sensitive neural cells in the retina. While current treatments may slow progression, they do not replace damaged tissue.

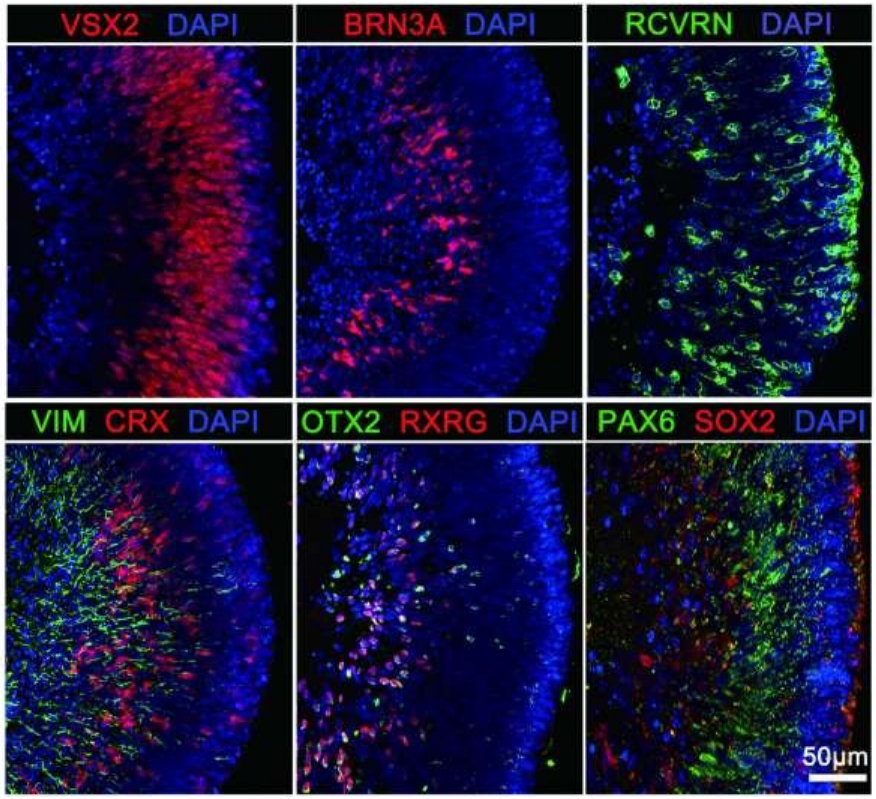
For decades, scientists have explored whether stem cells could be used to regenerate the retina, but the existence of true retinal stem cells in humans has remained uncertain. In fish and amphibians, the outer edge of the retina houses stem cells that regenerate tissue continuously. Whether a comparable system exists in the human eye has been debated for more than two decades.

In the study, "Identification and characterization of human retinal stem cells capable of retinal regeneration," published in *Science Translational Medicine*, researchers used single-cell and spatial transcriptomic methods to investigate the presence and identity of retinal stem-like cells in humans.

Researchers examined human fetal retinal tissue from four donors at 21 weeks of gestation, using spatial transcriptomics and single-nucleus sequencing to identify and localize cell types in the retina.

Researchers analyzed gene expression and chromatin accessibility to detect populations with stem cell–like properties. Additional samples from donors between 16 and 22 weeks of gestation were used to confirm the location of these cells in the peripheral retina.

A distinct population of neural retinal stem-like cells was identified in the peripheral retina of human fetal tissue. Located in the ciliary marginal zone, these cells showed molecular features consistent with self-renewal and the ability to differentiate into all major retinal cell types. Similar cells appeared in the same anatomical region of retinal organoids, with overlapping gene expression profiles.



Immunostaining of retinal organoid sections at repair stage day 40, highlighting different types of retinal cells. Credit: Jianzhong Su, State Key Laboratory of Eye Health, Eye Hospital, Wenzhou Medical University

Following injury in organoids, stem-like cells migrated into the damaged area and produced new retinal cells. Gene activity during the repair process matched patterns observed during natural fetal development.

In a mouse model of inherited retinal degeneration, transplanted cells remained viable for up to 24 weeks. Donor cells integrated into the host retina, developed into mature retinal types, and formed connections with neighboring cells. Treated animals exhibited improved retinal structure and stronger visual responses compared to controls.

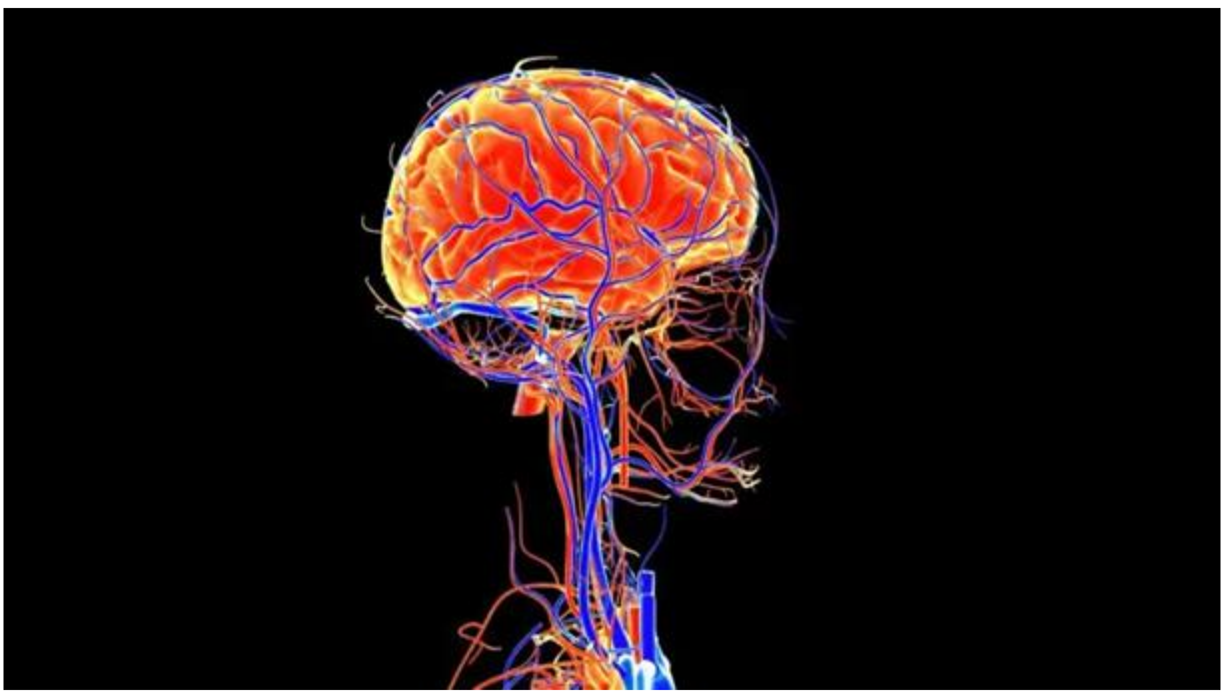
Human retinal stem-like cells demonstrated the capacity to regenerate tissue and restore visual function across both fetal tissue and retinal organoid models. In both injury models and transplant experiments, the cells demonstrated the ability to restore retinal structure and contribute to visual function.

Post-transplantation, the cells remained viable for at least 24 weeks, differentiated into photoreceptors, ganglion cells, and bipolar cells, and formed functional synapses with host tissue. Treated mice demonstrated improved retinal morphology and performance in visual function assays across multiple time points. No intraocular tumors were observed following transplantation.

Compared to previously studied retinal progenitor cells, this population showed broader differentiation capacity and longer-term viability. Transplanted cells contributed to retinal structure and restored visual function in mice, without adverse effects.

Results suggest that retinal organoids may serve as a source of human stem-like cells for future research and therapeutic development. Further studies will be needed to assess safety, immune compatibility, and effectiveness in models that more closely resemble human disease.

More information: Hui Liu et al, Identification and characterization of human retinal stem cells capable of retinal regeneration, *Science Translational Medicine* (2025). DOI: 10.1126/scitranslmed.adp6864
Journal information: Science Translational Medicine



The ability to think abstractly separates the human brain from that of other mammals. (Credit: Shot4Sell/Shutterstock)

Scientists observe possible 'foundation of human intelligence' for first time

In a nutshell

- Human brain neurons maintain consistent responses to people and objects regardless of context—unlike animal brains which show different neural responses to the same thing in different environments.
- This "context-independent" memory coding was observed in 97% of responsive neurons during memory formation and 100% during recall, suggesting a fundamental difference in how humans process information.
- This unique brain processing may explain why humans can think abstractly and transfer knowledge across different contexts—potentially revealing a key foundation of human intelligence.

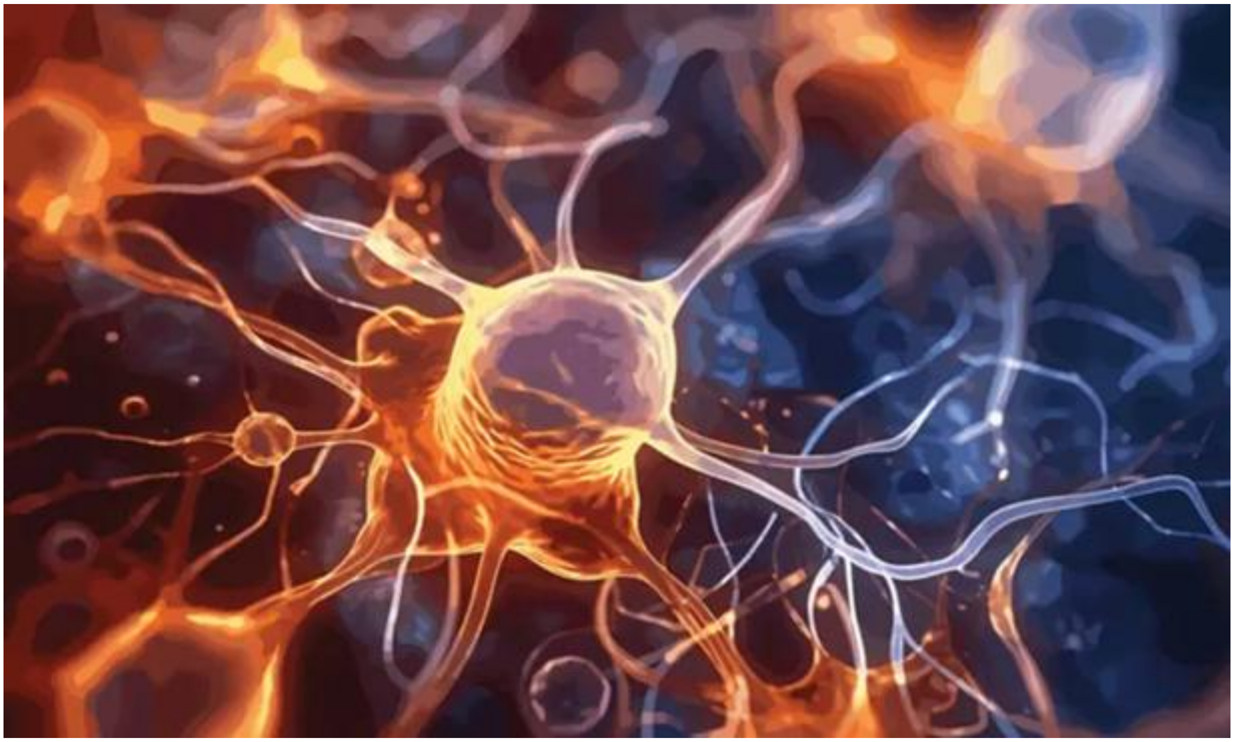
BARCELONA — For the first time, scientists have confirmed that the human brain processes memories in a way that's remarkably different from other species — a finding that may reveal a key foundation of human intelligence. Their research shows that individual neurons in the human brain represent concepts consistently, regardless of the context in which we encounter them. It's a stark contrast to what happens in the brains of rodents and monkeys.

This finding may help explain some uniquely human cognitive abilities, including our capacity for abstract thought, metacognition, and forming connections across vastly different situations. It indicates that the way our brains encode memories might be a key evolutionary adaptation that separates the human mind from that of other species.

"This context-invariant coding could be a key, unique feature of human intelligence," the researchers note in their paper.

More specifically, the study, published in *Cell Reports*, suggests this ability to maintain stable neural representations across different situations may be what enables our unique capacity for abstract thinking.

"The basic principle of neuronal coding in humans is the opposite of what has been observed in other species, which has significant implications," notes Dr. Rodrigo Quian Quiroga, who led the research at the Hospital del Mar Research Institute, in a statement. This fundamentally different approach to memory storage represents a radical departure from existing neuroscience models.



A 3D rendering of neurons and how they connect and communicate through synaptic connections. (credit: Sanford Burnham Prebys)

Why Neuronal Behavior Matters

The research team studied the activity of individual neurons in the brains of nine epilepsy patients who had electrodes implanted as part of their treatment. This rare opportunity allowed the scientists to observe how single neurons behave when forming and recalling memories—something that cannot be done with standard brain imaging techniques.

The study revealed something unexpected: When a neuron responded to a specific person (like the Argentinian TV host Diego Topa used in one example), it fired in almost exactly the same way regardless o f whether that person appeared in story context A or story context B. This contradicts decades of animal research showing that neurons in other species significantly modify their firing patterns based on context.

When a rat encounters a familiar object in two different locations, its brain activates different sets of neurons—essentially creating separate memories for the same object in different contexts. This has been well-documented across animal studies.

Human brains, however, appear to work differently. Our neurons recognize concepts consistently, regardless of where we encounter them. It's as though our brains prioritize the "what" over the "where" or "when."

How the Study Worked

The researchers used a clever experimental design to investigate this phenomenon. Patients learned and recalled four simple stories, with two different stories featuring the same person in entirely different contexts. By recording the activity of individual neurons as participants learned and recalled these stories, the scientists could directly observe how context influenced neural responses.

Incredibly, nearly all neurons (97% during encoding and 100% during recall) maintained consistent firing patterns regardless of which story context was being processed. The neurons fired robustly to the presence of a specific person regardless of where they appeared in the narrative.

This consistency held true across different tasks as well. The same neurons activated whether participants were passively viewing images of people, actively learning stories about them, or recalling those stories from memory.

The researchers also looked for evidence of "conjunctive coding"—neurons that might fire only to specific combinations, such as "Jackie Chan at the waterfall" but not "Jackie Chan at another location." Such conjunctive coding is common in animal studies but was almost entirely absent in the human participants. Less than 1% of neurons showed any evidence of responding to specific person-context combinations.

Statistical models built by the team could successfully predict which person a participant was processing but failed to predict which specific story context was involved—further evidence that the neural representations were context-independent.

A New Perspective of Human Intelligence

"Memories are stored in a much more abstract manner in humans compared to other animals. You can think of concepts or anything else in more abstract terms, independent of the context in which you learned them," explains Dr. Quian Quiroga, suggesting that this could be one of the "foundations of human intelligence."

This ability to maintain consistent mental representations across different contexts might be what enables humans to think abstractly and make connections between seemingly unrelated scenarios.

"This ability allows us to make much more abstract and complex associations and inferences than if we were forced to think of each concept within a specific, concrete context," Dr. Quian Quiroga asserts. "In other words, humans can decontextualize their memories to create more abstract thought."

These findings challenge the prevailing view that human memory works similarly to that of other mammals, just with greater complexity. Instead, they point to a key difference in information processing that could help explain uniquely human cognitive abilities.

This mechanism might be what allows us to recognize the same person in completely different contexts, take lessons learned in one domain and apply them to entirely different scenarios, or understand abstract concepts like justice or democracy regardless of the specific examples we encounter.

The human brain, it seems, plays by different rules than we've long believed—rules that might help explain our unique place in the animal kingdom.

Paper Summary

Methodology

The study examined nine epilepsy patients who had electrodes implanted in their brains as part of their clinical treatment. These electrodes allowed direct recording from the hippocampus and amygdala, brain regions crucial for memory formation. Patients first viewed over 100 pictures to identify which stimuli triggered responses in specific neurons. Researchers then created four stories with similar structures, where two stories featured one person in different contexts, and two featured another person in different contexts. Participants learned these stories through repeated presentations and then recalled them when prompted. By recording brain activity during both learning and recall, researchers could directly observe how individual neurons responded to the same person in different narrative contexts.

Results Breakdown

The key findings revealed that human memory neurons behave consistently across contexts. Out of all neurons that responded to a specific person during memory encoding, 97% showed no significant difference in their response when that person appeared in two completely different story contexts. During recall, this consistency rose to 100%. The team could predict which person a participant was thinking about with 84% accuracy during encoding and 75% during recall but could not reliably determine which specific story context was being processed. This provided strong evidence that human memory neurons maintain consistent responses regardless of context—a fundamental difference from how animal brains process memories.

Limitations

This study has important limitations to consider. The small sample of nine epilepsy patients may not represent how all human brains function. The recordings were limited to specific brain regions determined by clinical needs. The researchers used familiar identities in their design, and it remains unknown whether novel, unfamiliar stimuli would show similar patterns. During the encoding phase, identical pictures were used across different stories, which might have influenced the results, though similar findings were observed during recall when no pictures were shown.

Discussion and Takeaways

The significance of this research extends beyond basic neuroscience. The authors suggest that context-invariant neural coding might explain uniquely human cognitive abilities. While the hippocampus is known to be critical for context-dependent memories across species, the mechanisms appear to differ fundamentally in humans. Rather than neurons changing their firing patterns based on context, humans might represent different contexts through the co-activation of different neuronal assemblies, each encoding specific elements in a context-independent way. This mechanism could facilitate metacognition (thinking about thoughts independent of specific contexts), making inferences across diverse situations, and generalizing concepts across contexts – all hallmarks of human intelligence. The authors suggest this might reflect an evolutionary adaptation connected to language, which allows humans to think about meaning independently from specific sensory experiences. This discovery challenges prevailing models of memory that assume human memory works similarly to that of other mammals but with greater complexity. Instead, it suggests a qualitatively different information processing approach that may help explain the unique nature of human cognition.

Funding and Disclosures

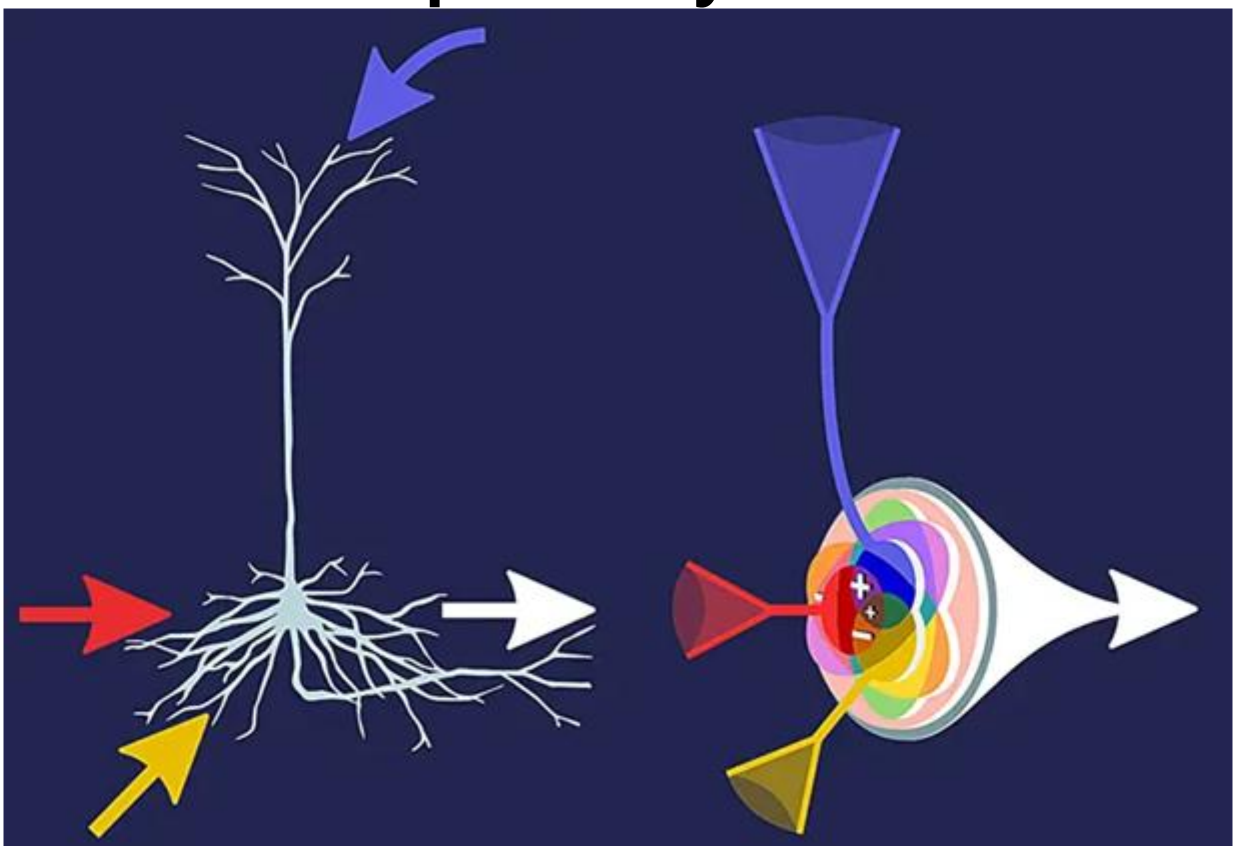
The research was supported by grants from several organizations including the Medical Research Council, the Biotechnology and Biological Sciences Research Council, the Human Frontiers Science Project, the Royal Society, and CONICET (Argentina's National Scientific and Technical Research Council). The authors declared no competing interests related to the research.

Publication Information

The study, titled "Lack of context modulation in human single neuron responses in the medial temporal lobe," was authored by Hernan G. Rey, Theofanis I. Panagiotaropoulos, Lorenzo Gutierrez, Fernando J. Chaure, Alejandro Nasimbera, Santiago Cordisco, Fabian Nishida, Antonio Valentin, Gonzalo Alarcon, Mark P. Richardson, Silvia Kochen, and Rodrigo Quian Quiroga. It was published in *Cell Reports* (Volume 44, 115218) on January 28, 2025. The research represents a collaborative effort involving scientists from the University of Leicester (UK), Medical College of Wisconsin (USA), INSERM (France), University of Buenos Aires

(Argentina), ENyS CEMET (Argentina), King's College London (UK), Royal Manchester Children's Hospital (UK), El Cruce Hospital (Argentina), Hospital Del Mar Medical Research Institute (Spain), and several other institutions.

Self-organizing 'infomorphic neurons' can learn independently



Living neurons receive signals from different sources, process them and pass an output signal on to other neurons (left). In the artificial neuron model, this information processing can be described and improved by a learning objective (right). Similar to their biological models, this independent learning allows novel artificial neurons to solve tasks in a self-organized way. Credit: Andreas Schneider, MPI-DS

Researchers have developed "infomorphic neurons" that learn independently, mimicking their biological counterparts more accurately than previous artificial neurons. A team of researchers from the Göttingen Campus Institute for Dynamics of Biological Networks (CIDBN) at the University of Göttingen and the Max Planck Institute for Dynamics and Self-Organization (MPI-DS) has programmed these infomorphic neurons and constructed artificial neural networks from them.

The special feature is that the individual artificial neurons learn in a self-organized way and draw the necessary information from their immediate environment in the network. Their findings are published in the journal *Proceedings of the National Academy of Sciences*.

Both the human brain and modern artificial neural networks are extremely powerful. At the lowest level, the neurons work together as rather simple computing units.

An artificial neural network typically consists of several layers composed of individual neurons. An input signal passes through these layers and is processed by artificial neurons in order to extract relevant information. However, conventional artificial neurons differ significantly from their biological models in the way they learn.

While most artificial neural networks depend on overarching coordination outside the network in order to learn, biological neurons only receive and process signals from other neurons in their immediate vicinity in the network. Biological neural networks are still far superior to artificial ones in terms of both flexibility and energy efficiency.

The new artificial neurons, known as "infomorphic neurons," are capable of learning independently and self-organizing among their neighboring neurons. This means that the smallest unit in the network has to be controlled no longer from the outside, but decides itself which input is relevant and which is not.

In developing the infomorphic neurons, the team was inspired by the way the brain works, especially by the pyramidal cells in the cerebral cortex. These also process stimuli from different sources in their immediate environment and use them to adapt and learn. The new artificial neurons pursue very general, easy-to-understand learning goals.

"We now directly understand what is happening inside the network and how the individual artificial neurons learn independently," emphasizes Marcel Graetz from CIDBN.

By defining the learning objectives, the researchers enabled the neurons to find their specific learning rules themselves. The team focused on the learning process of each individual neuron.

They applied a novel information-theoretic measure to precisely adjust whether a neuron should seek more redundancy with its neighbors, collaborate synergistically, or try to specialize in its own part of the network's information.

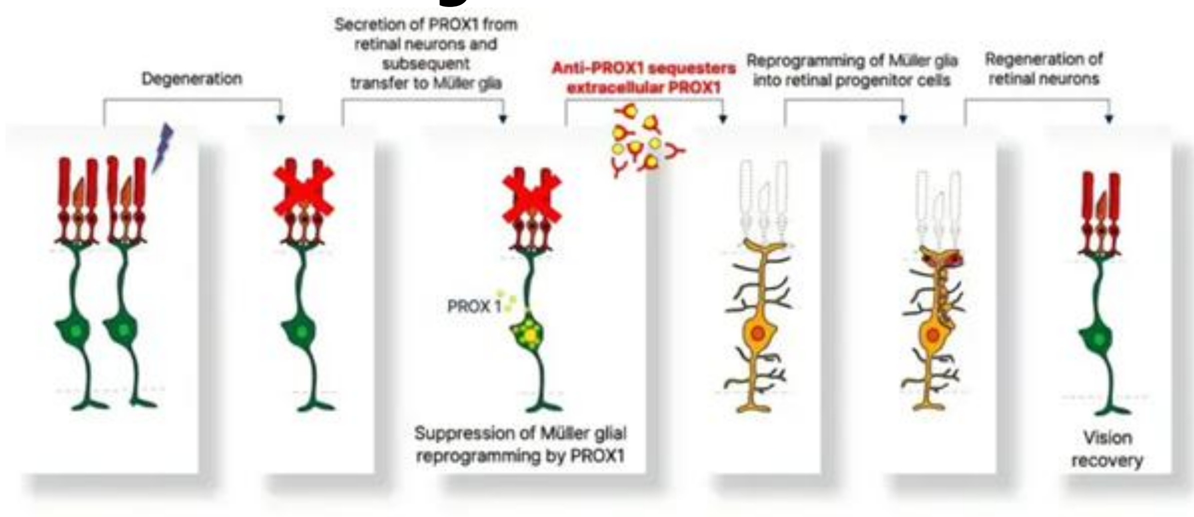
"By specializing in certain aspects of the input and coordinating with their neighbors, our infomorphic neurons learn how to contribute to the overall task of the network," explains Valentin Neuhaus from MPI-DS.

With the infomorphic neurons, the team is not only developing a novel method for machine learning, but is also contributing to a better understanding of learning in the brain.

More information: Abdullah Makkeh et al, A general framework for interpretable neural learning based on local information-theoretic goal functions, *Proceedings of the National Academy of Sciences* (2025). DOI: 10.1073/pnas.2408125122

Provided by Max Planck Society

Vision restored: Retinal therapy research marks first successful induction of long-term neural regeneration



Schematic diagram of the mechanism of retinal regeneration through inhibition of PROX1 migration. PROX1 protein secreted from damaged retinal nerve cells migrates to Müller glia and inhibits dedifferentiation into neural progenitor cells and neural regeneration. When PROX1 is captured outside the cells with a neutralizing antibody against PROX1 and its migration to Müller glia is inhibited, dedifferentiation of Müller glia cells and neural cell regeneration processes are resumed, restoring retinal function. Credit: Nature Communications (2025). DOI: 10.1038/s41467-025-58290-8

Vision is one of the most crucial human senses, yet more than 300 million people worldwide are at risk of vision loss due to various retinal diseases. While recent advancements in retinal disease treatments have successfully slowed disease progression, no effective therapy has been developed to restore already lost vision—until now.

KAIST researchers led by Professor Jinwoo Kim from the Department of Biological Sciences have successfully developed a novel drug to restore vision through retinal nerve regeneration. The research is published in the journal *Nature Communications*. The study was co-authored by Dr. Eun Jung Lee of Celliaz Inc. and Museong Kim, a Ph.D. candidate at KAIST, as joint first authors.

The research team successfully induced neural regeneration and vision recovery in a disease-model mouse by administering a compound that blocks the PROX1 (Prospero Homeobox 1) protein, which suppresses retinal regeneration. The effect lasted for more than six months.

This study marks the world's first successful induction of long-term neural regeneration in mammalian retinas, offering new hope to patients with degenerative retinal diseases who previously had no treatment options.

As the global population continues to age, the number of retinal disease patients is steadily increasing. However, no treatments exist to restore damaged retinas and vision. The primary reason for this is the mammalian retina's inability to regenerate once damaged.

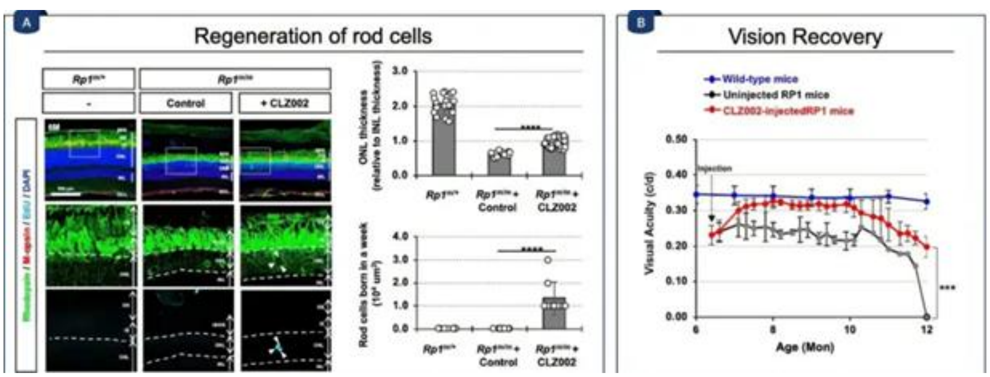
Studies on cold-blooded animals, such as fish—known for their robust retinal regeneration—have shown that retinal injuries trigger Müller glia cells to dedifferentiate into neural progenitor cells, which then generate new neurons. However, in mammals, this function is lost, leading to permanent retinal damage.

Through this study, the research team identified the PROX1 protein as a key inhibitor of Müller glia dedifferentiation in mammals. PROX1 is a protein found in neurons of the retina, hippocampus, and spinal cord, where it suppresses neural stem cell proliferation and promotes differentiation into neurons.

The researchers discovered that PROX1 accumulates in damaged mouse retinal Müller glia, but is absent in the highly regenerative Müller glia of fish. Furthermore, they demonstrated that the PROX1 found in Müller glia is not synthesized internally but rather taken up from surrounding neurons, which fail to degrade and instead secrete the protein. Based on this finding, the team developed a method to restore Müller glia's regenerative ability by eliminating extracellular PROX1 before it reaches these cells. This approach involves using an antibody that binds to PROX1, discovered by Celliaz Inc., a biotech startup founded by Professor Jinwoo Kim's research lab. This PROX1-neutralizing antibody exhibited superior binding affinity compared to existing antibodies. When administered to disease-model mouse retinas, this antibody significantly promoted neural regeneration. Additionally, when delivered as a type of gene therapy in mice with congenital retinal degeneration, it enabled sustained neuronal production and vision restoration for over six months.

The retinal regeneration-inducing therapy is currently being developed by Celliaz Inc. for application in various degenerative retinal diseases that currently lack effective treatments. The company aims to begin clinical trials by 2028.

Dr. Eun Jung Lee stated, "We are finalizing improvements to the efficacy of the PROX1-neutralizing antibody (CLZ001) and aim to complete vision restoration efficacy and safety evaluations in multiple animal models before administering it to retinal disease patients. Our goal is to provide a real solution for patients at risk of blindness who currently lack proper treatment options."



Retinal regeneration and visual recovery in a retinitis pigmentosa model mouse through administration of AAV2-Anti-PROX1 gene therapy. We demonstrate that after administration of adeno-associated virus (AAV2-Anti-PROX1) expressing PROX1 neutralizing antibodies to the eyes of RP1 retinitis pigmentosa model mice with vision loss, the photoreceptor cell layer of the retina is restored (A) and vision is restored (B). Credit: Nature Communications (2025). DOI: 10.1038/s41467-025-58290-8 **More information:** Eun Jung Lee et al, Restoration of retinal regenerative potential of Müller glia by disrupting intercellular Prox1 transfer, *Nature Communications* (2025). DOI: 10.1038/s41467-025-58290-8

Provided by The Korea Advanced Institute of Science and Technology (KAIST)

Cutting-edge wearable device mimics the complexity of human touch

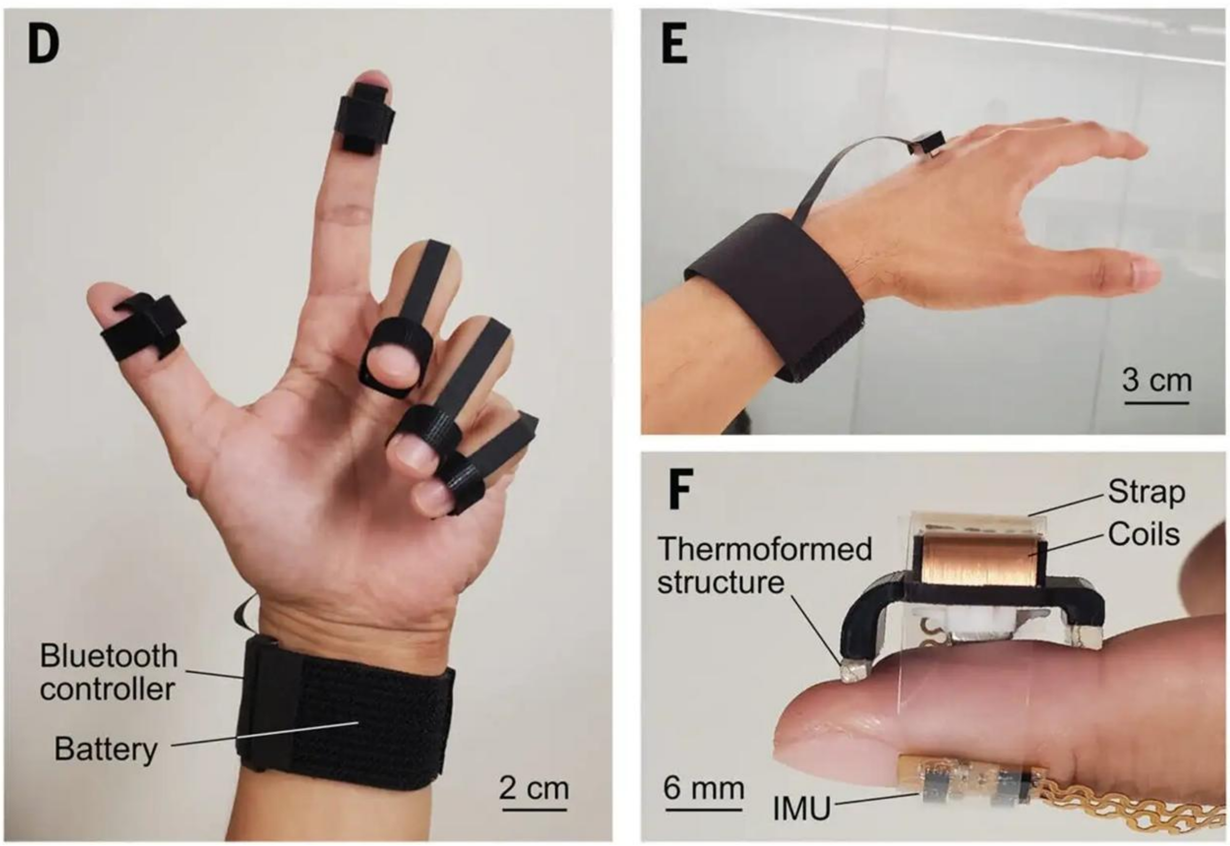
Cutting-edge wearable device mimics human touch

©Science

The sense of touch gives you vital information about the world around you. From gripping a coffee mug to shaking hands or feeling fabric, touch helps you interact with objects and people. Beneath your skin, a network of sensors called mechanoreceptors detects vibrations, pressure, stretch, and movement.

These receptors work together to deliver a complex, layered experience that goes far beyond a simple buzz.

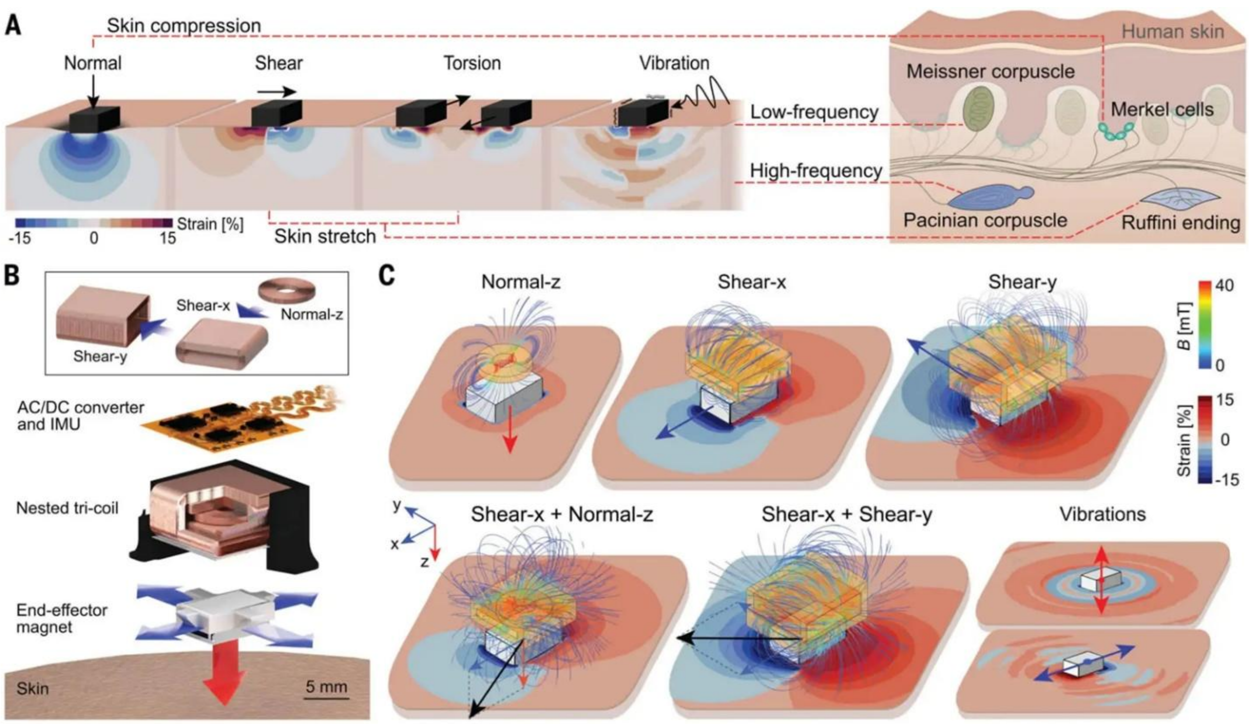
Now, a breakthrough in haptic technology could bring that same level of complexity into the digital world. Engineers from Northwestern University have developed a tiny, wireless device that mimics the real feeling of touch in virtual environments. Unlike most current devices that just vibrate, this new technology can push, pull, twist, or slide across your skin — even combine different movements — for a realistic and customizable touch experience.



The new actuator, developed by engineers at a top research university, brings something never before seen in haptic devices: full freedom of motion. That means it can move and apply force in all directions — up, down, side to side, and even in circles. Measuring just a few millimeters, the compact, battery-powered device can be placed anywhere on your body. It connects wirelessly to virtual reality systems, phones, or wearables and can work solo or as part of an array.

“Almost all haptic actuators really just poke at the skin,” said one of the lead researchers. “But skin is receptive to much more sophisticated senses of touch. We wanted to create a device that could apply forces in any direction — not just poking but pushing, twisting and sliding.”

Instead of building on older ideas like motor vibrations or simple pressure pads, the team designed a whole new system. It uses magnets and coils that interact to generate a force. As electric current flows through the coil, it creates a magnetic field that pushes or pulls the magnet in different directions. The result is a wide range of tactile effects — stretching, tapping, sliding, or rotating — all of which can be programmed with precision.



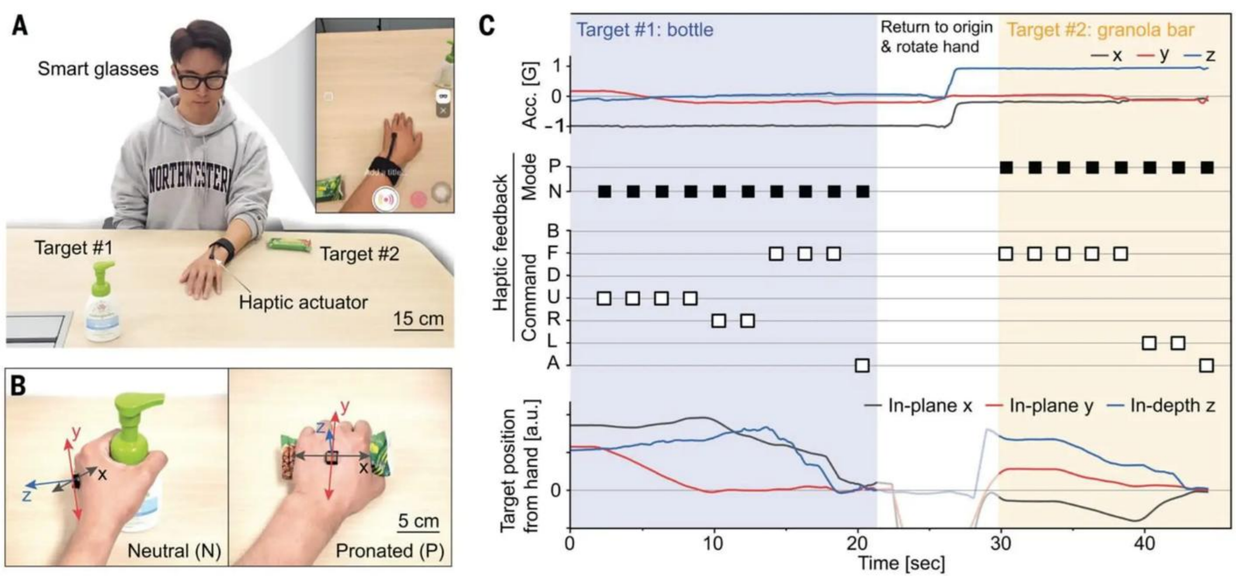
Why previous haptics fell short

©Science

In recent years, technology has made huge leaps in sound and visuals. Ultra-sharp screens, 3D audio, and virtual reality goggles can now deliver rich, immersive experiences. But touch technology — known as haptics — hasn’t kept up. Most systems still rely on basic vibration motors like those found in phones or gaming controllers.

The reason is simple: human touch is extremely complex. Inside your skin are four major types of mechanoreceptors. Each one responds to different forces and frequencies — some to deep pressure, others to light brushing or steady vibrations. These sensors send signals to your brain, creating the rich, detailed experience of touch.

Simulating those signals with machines has been a challenge. Earlier approaches used motors, air pumps, shape-memory alloys, or static charges to try to recreate sensations. But each method had trade-offs. Some were too big or heavy. Others couldn't respond fast enough or couldn't be arranged across large parts of the body. None could generate the full range of sensations needed for realistic experiences in extended reality, or XR.



Feeling the digital world

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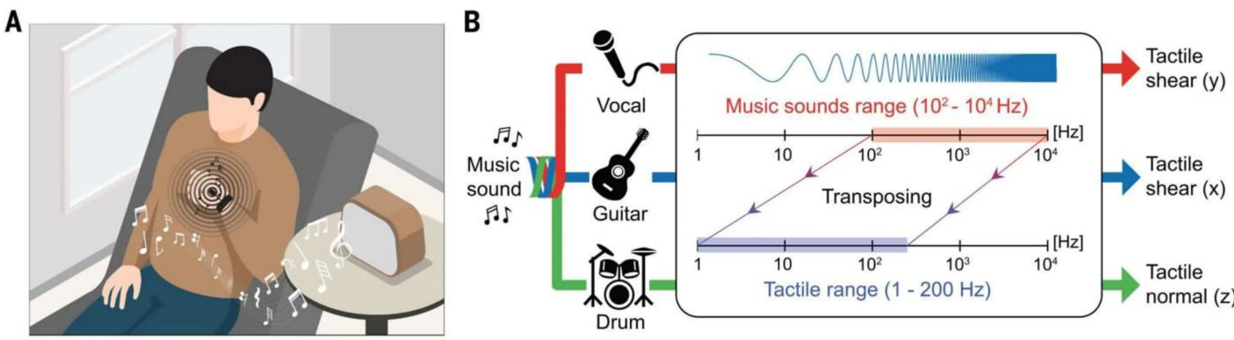
To overcome this, the team built their actuator to mimic how your skin actually responds in real life. By combining motion and direction, they were able to trigger all four types of mechanoreceptors — either one at a time or together. They also built in an accelerometer that tracks how the device moves through space. That allows the system to adjust feedback based on how fast or where your hand is moving.

If you touch a silk scarf, for example, your finger glides smoothly and quickly. But if you run your finger over corduroy, there's more friction and resistance. The actuator can mimic these differences by changing the direction, force, and timing of its motion. This means digital objects can "feel" more like the real thing.

"You can imagine shopping for clothes or fabrics online and wanting to feel the texture," said the lead developer. "If you run your finger along a piece of silk, it will have less friction and slide faster than when touching corduroy or burlap."



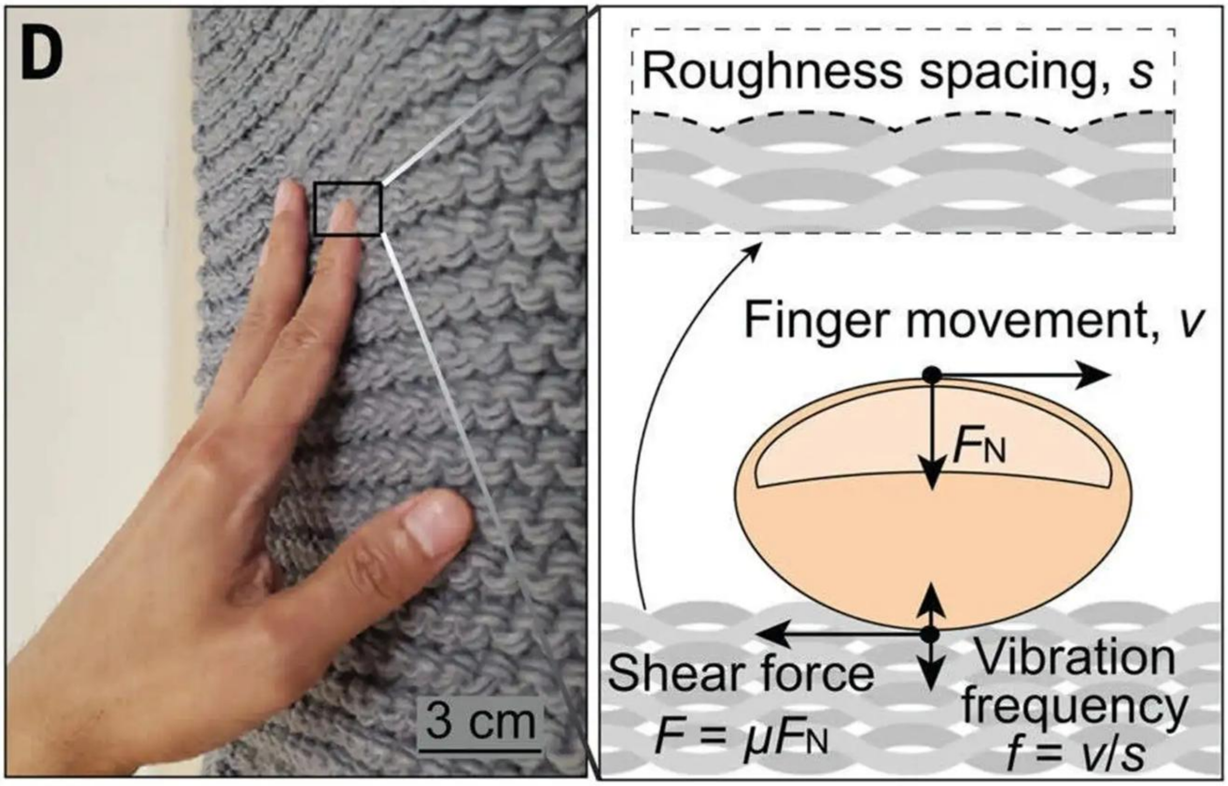
More than just entertainment

©Science

While this new haptic actuator could make gaming and virtual reality feel more lifelike, its impact could reach far beyond entertainment. In health care, it could allow doctors to give better virtual check-ups by transmitting tactile cues. For those with limb loss or disabilities, it could serve as a tool for sensory replacement or enhancement. Combined with cameras or sensors, it could even help blind users "see" their surroundings through touch.

The system also supports closed-loop feedback, meaning it can send and receive signals. That opens doors to advanced teleoperations — like controlling robots or medical tools from a distance with real-time physical feedback. In rehab settings, it could help retrain patients to move or feel again by delivering touch stimuli as part of therapy.

“Achieving both a compact design and strong force output is crucial,” said one researcher who helped create the model. “Our team developed analytical models to ensure each mode of actuation generates maximum force while avoiding unwanted side effects.”



The science and applications of real touch

©Science

Your skin has four types of mechanoreceptors that respond to touch in unique ways. Some detect light brushing, others respond to vibrations, deep pressure, or slow stretching. These sensors send signals to your brain, helping you recognize shapes, textures, and temperatures.

To create a real sense of touch, a haptic device must stimulate these receptors accurately — and in the right sequence. This new actuator does exactly that by applying programmable forces in many directions and speeds. It doesn't just poke the skin. It moves in all directions and does so with precise control.

From online retail to remote health care, this new device has wide potential. Users could feel the fabric of clothes before buying them online. Surgeons could "touch" patients in virtual check-ups. Even social media might change, offering hugs, handshakes, or high-fives you can feel through your screen.

The researchers also see applications in music and entertainment. By translating sound into touch, the technology could create new experiences for people with hearing loss or enhance music in gaming and XR.

Despite its power, the actuator stays small and efficient. It runs on a rechargeable battery and connects through Bluetooth. That means it can pair with devices you already use, like a smartphone or VR headset. And it can be worn anywhere on the body — not just on fingers — offering full-body feedback.

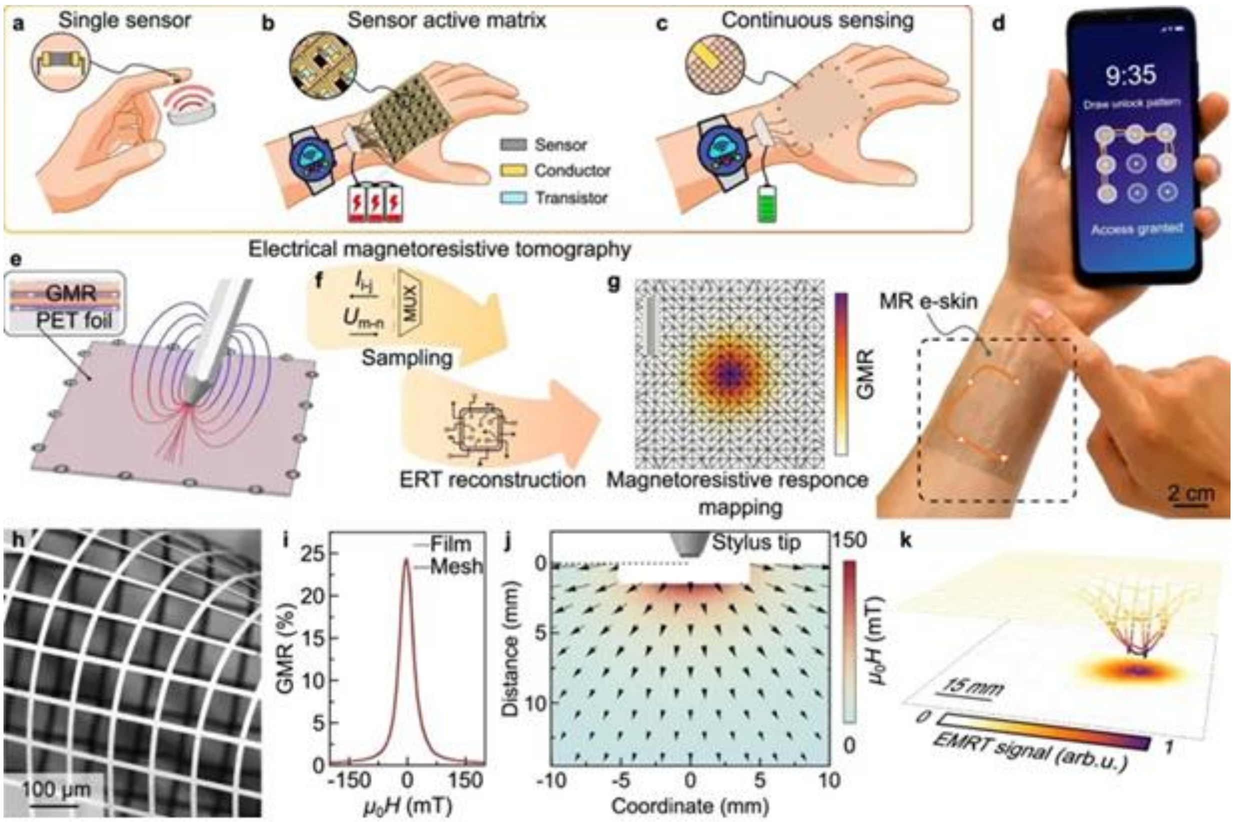
Smartest electronic skin with 'brain' could be magnetic miracle for humans, robots

Scientists at a German research lab have created an ultra-thin, flexible electronic skin (e-skin) that can detect and track magnetic fields using a single global sensor.

Unlike previous designs that required multiple sensors and electronics, this new e-skin is more energy-efficient and mimics how human skin interacts with the brain.

What makes this innovation more exciting is that it enables touchless interactions. So, using this e-skin, you could operate devices in wet, extreme, or sensitive environments (like underwater or in sterile labs).

This e-skin has the potential to give robots a sense of touch through magnetic fields, allow humans to interact with digital environments (virtual reality) without any physical controllers, and help people with sensory impairments regain certain abilities.



A diagram showing the magnetic sensitivity of the e-skin. Source: Makushko, P., Ge, J., Cañón Bermúdez, G.S. et al./Nature Communications (2025)

Traditional e-skins rely on multiple sensors, batteries, and electronic components, making them bulky, power-hungry, and impractical. To overcome these limitations, the researchers designed an e-skin that works more like human skin.

It has three components: First is the ultra-thin, flexible membrane that acts as the base structure of the e-skin. It is made of a lightweight, transparent, and breathable material that allows air and moisture to pass through so the real skin underneath can breathe.

The second is a magnetosensitive layer that covers the entire surface of the electronic skin. It detects and processes magnetic signals using a single analysis unit, similar to how human skin sends signals to the brain.

So, whenever the e-skin comes near a magnetic source, the magnetosensitive layer reacts, causing a change in the electrical resistance of the material. This change is picked up by the central processing unit, the third component, which then determines the exact location of the magnetic source.

Basically, the magnetosensitive layers “work like a single global sensor surface — just like our skin, and the single central processing unit reconstructs the signal — just like our brain,” the study authors note.

For accuracy in source detection, the e-skin utilizes a tomography-based signal processing method. This approach is inspired by MRI and CT scan techniques; it helps refine the accuracy of the signal by analyzing multiple data points, similar to how medical imaging methods reconstruct a detailed image from different angles.

“This technology is new for e-skins with magnetic field sensors – it was previously considered too insensitive for a low signal contrast of conventional magnetosensitive materials. The fact that we validated this method experimentally is a major technical achievement of the work,” Pavlo Makushko, lead researcher and a scientist at Helmholtz-Zentrum Dresden-Rossendorf (HZDR), said.

One skin, many applications

What makes the novel e-skin developed by the HZDR team special is that it mimics how the real human skin and the brain work together to process touch. Previous e-skins struggled to track magnetic signals accurately because traditional materials had low signal contrast.

The use of tomography solves this problem. Moreover, it can be used by both humans and machines, making it a highly practical innovation.

For example, it could allow a user to control their phone with a magnetic patch on a glove, even in freezing weather or amidst heavy rainfall.

Moreover, An e-skin with a human-like touch and great magnetic sensitivity could make robots better equipped for tasks such as cooking, rescue operations, deep-sea explorations, patient care, etc.

Further, “blind individuals equipped with the magnetoreceptor system could extend the distance of their perception, and those with prosthetic hands could use it to interact with smartphones, overcoming the challenge of insulated prosthetics not being able to interact with capacitive touchscreens," the study authors added.

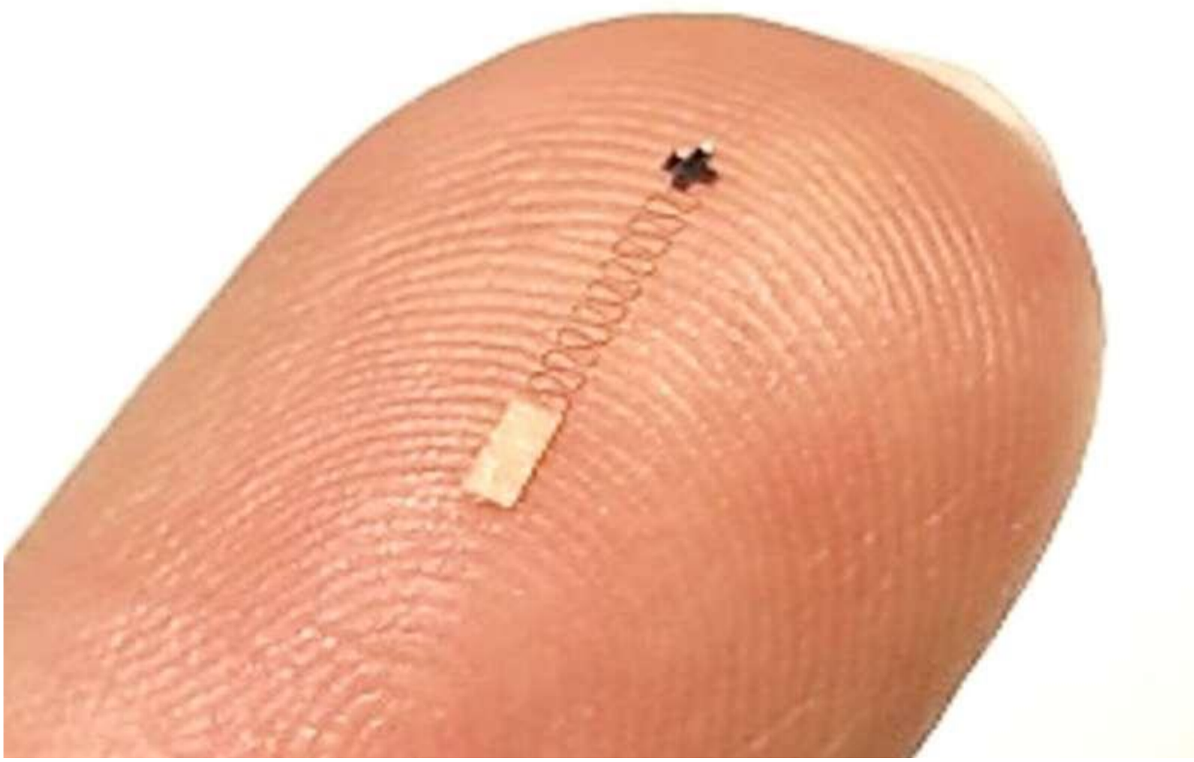
There could be many other possibilities. This e-skin could soon become commercially available and change the way we interact with everything around us.

The study is published in the journal *Nature Communications*.

APRIL 8, 2025

Microscale brain–computer interface is small enough to be placed between hair follicles

by Bob Yirka , Medical Xpress

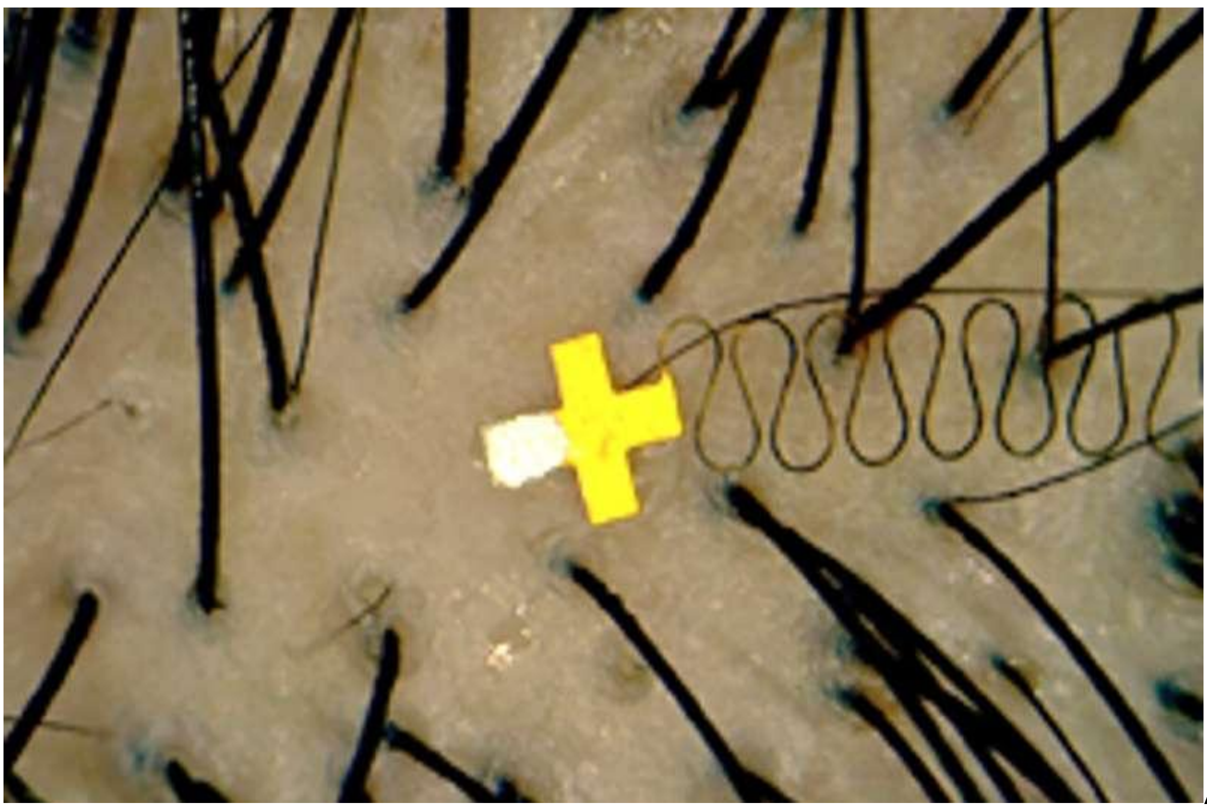


A microscale brain sensor on a finger. Credit: W. Hong Yeo

A team of engineers at Georgia Institute of Technology's Wearable Intelligent Systems and Healthcare Center, working with colleagues affiliated with several institutions in South Korea, has developed a microscale brain–computer interface that is small enough to be placed between hair follicles on a user's head.

In their paper published in the *Proceedings of the National Academy of Sciences*, the group describes how they made their interface, how it attaches to other hardware to allow readings to be captured and how well it worked during testing.

Over the past several decades, brain–computer interfaces have been developed that are capable of reading brain waves and responding to them in useful ways. These devices can be used to control a cursor on a computer screen, for example, or to choose buttons to press. Such devices are still in limited use, however, mainly due to their bulky nature. In this new effort, the researchers have developed a sensor so small it can be placed on the scalp between hair follicles.



A microscale brain sensor placed between hair follicles. Credit: W. Hong Yeo

The sensors are made of cross-shaped resin with microscale spikes. The spikes poke through some of the skin when the sensor is pushed onto the scalp. Each sensor is also connected to what the team describes as a serpentine interconnector, which is a squiggly wire. The wire snakes its way through the hair to a microprocessor that sends the brain signals wirelessly to the device that the brain signals will control.

The research team tested their system two ways. In the first, they broadcast user brainwaves to a computer running a telephone application. In the second, they sent the brain signals to a pair of glasses worn by the user that served as a small display. The display was then used to control a smartphone application.

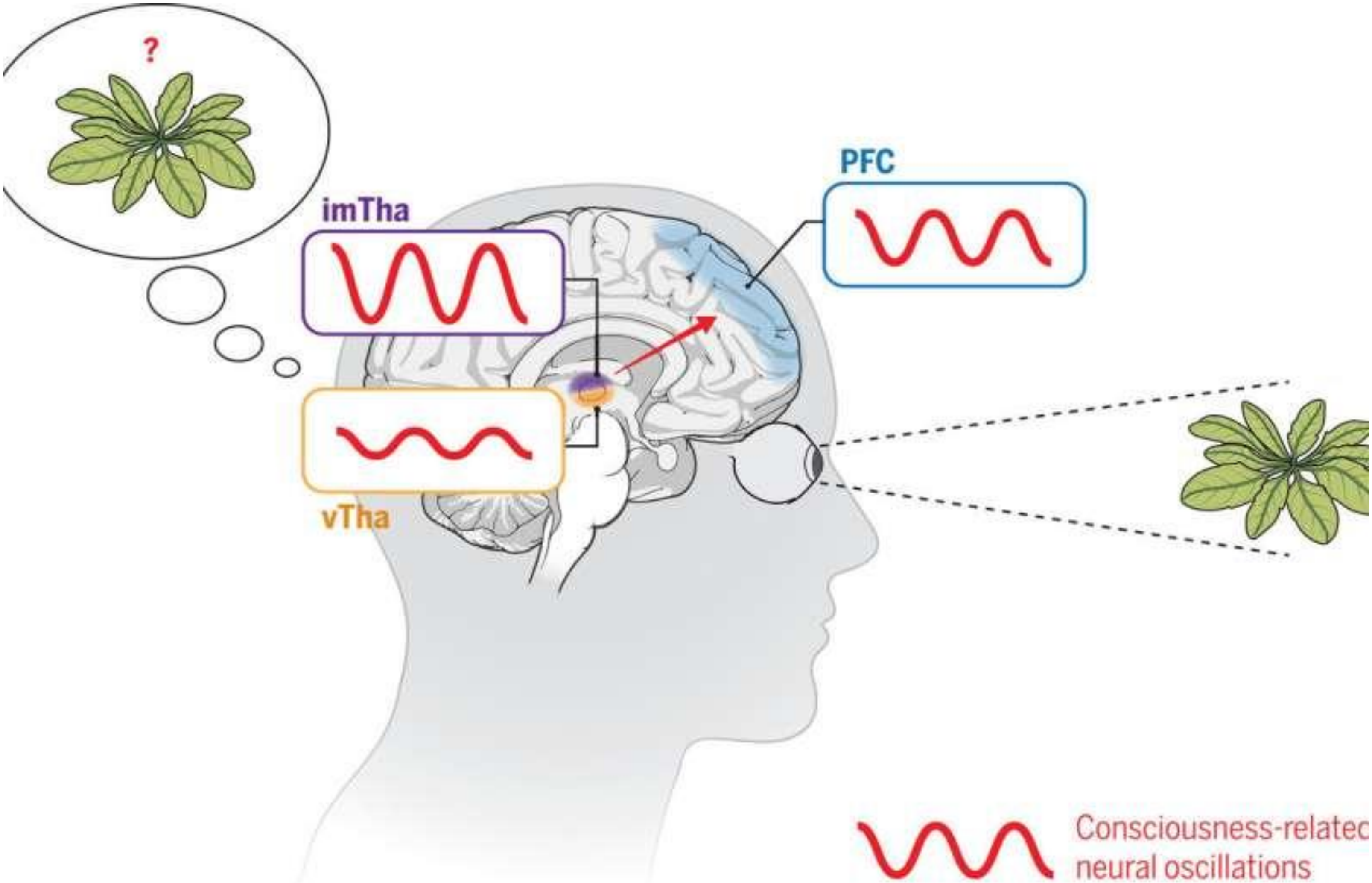
During testing, the team found their system was approximately 96.4% accurate and that it remained stable and in place for up to 12 hours. They conclude by noting that their interface was designed in such a way to allow mass production, possibly making it available for millions of disabled people in the coming years.

More information: Hodam Kim et al, Motion artifact–controlled micro–brain sensors between hair follicles for persistent augmented reality brain–computer interfaces, *Proceedings of the National Academy of Sciences* (2025). DOI: 10.1073/pnas.2419304122
Journal information: Proceedings of the National Academy of Sciences

APRIL 8, 2025

Thalamic nuclei observed driving conscious perception

by Justin Jackson , Medical Xpress



The intralaminar and medial thalamic nuclei (imTha) play a gate role in human conscious perception. Credit: *Science* (2025). DOI: 10.1126/science.adr3675

Beijing Normal University-led researchers have identified specific high-order thalamic nuclei that drive human conscious perception by activating the prefrontal cortex. Their findings enhance understanding of how the brain forms conscious experience, offering new empirical support for theories that assign a central role to thalamic structures rather than cortical areas alone.

Consciousness has been described as existing in two distinct forms: the general state of being awake or asleep, and the specific contents of subjective awareness. Most studies investigating the neural basis of perception have focused on the cerebral cortex.

Subcortical structures, including high-order thalamic nuclei, remain comparatively unexplored, ill-accounting for how rapidly shifting sensory information becomes part of conscious experience.

Previous work has often considered thalamus function only as a relay for sensory input, rather than as a direct participant in generating conscious perception. Yet anatomical studies have shown widespread thalamic connections to brain regions linked to awareness. Several theoretical frameworks propose that thalamocortical loops may carry out essential integration functions for perception.

Functional imaging methods lack the spatial and temporal precision to observe subsecond neural events in deep brain regions. Whether there are contributions from distinct thalamic nuclei interactions with the cortex during conscious perception has therefore remained hidden from observation.

In the study, "Human high-order thalamic nuclei gate conscious perception through the thalamofrontal loop," published in *Science*, researchers performed direct recordings from both thalamic and cortical areas in human subjects as a way to examine the timing and structure of these interactions in real time.

Stereoelectroencephalography (sEEG) recordings were taken from five adult patients undergoing evaluation for deep brain stimulation as part of treatment for drug-resistant headaches. Each patient had electrodes surgically implanted across multiple thalamic nuclei and regions of the prefrontal cortex. In total, 194 recording sites were located in nine distinct thalamic nuclei, and 213 in the prefrontal cortex.

A visual awareness task was used to distinguish neural signals related to conscious perception from those associated with other cognitive functions.

Subjects viewed brief presentations of faint black-and-white grating patterns, appearing for 50 milliseconds at peripheral locations and varying in contrast, to test conscious awareness via directional eye movements. The visual method was selected over physical or audible versions to reduce interference from motor planning or verbal reporting tasks.

Consciousness-related neural activity emerged earlier and with greater intensity in intralaminar and medial thalamic nuclei than in ventral thalamic nuclei or the prefrontal cortex. Recordings revealed that activity in these high-order nuclei preceded corresponding signals in cortical areas by several dozen milliseconds. This timing pattern was observed consistently across participants and trial types.

A total of 108 thalamic recording sites showed statistically significant differences between conscious and unconscious visual trials.

The majority of early responses, defined as divergence onset times within 350 milliseconds of stimulus presentation, originated in the central medial, mediodorsal medial, and parafascicular nuclei. These same nuclei showed higher event-related potential amplitudes and greater increases in low-frequency spectral power during conscious perception than the ventral anterior, ventral lateral, and ventral posterolateral groups.

Phase synchrony measurements revealed that consciousness-related low-frequency oscillations, particularly in the theta band (2 to 8 Hz), originated in intralaminar and medial nuclei. Oscillations propagated outward in a temporal sequence: first appearing within the thalamus, then in connections between thalamus and prefrontal cortex, and last within the cortex.

Consciousness-related phase-amplitude coupling, a type of brain signal coordination where slower brain rhythms influence the strength of faster ones, was stronger during conscious perception and emerged first in thalamic regions.

Signals from intralaminar and medial nuclei showed coupling between low-frequency phases and high-frequency amplitudes in the lateral prefrontal cortex, a pattern not present in unconscious trials. This cross-frequency interaction also originated in the thalamus and appeared earlier and more strongly than similar activity within the cortex.

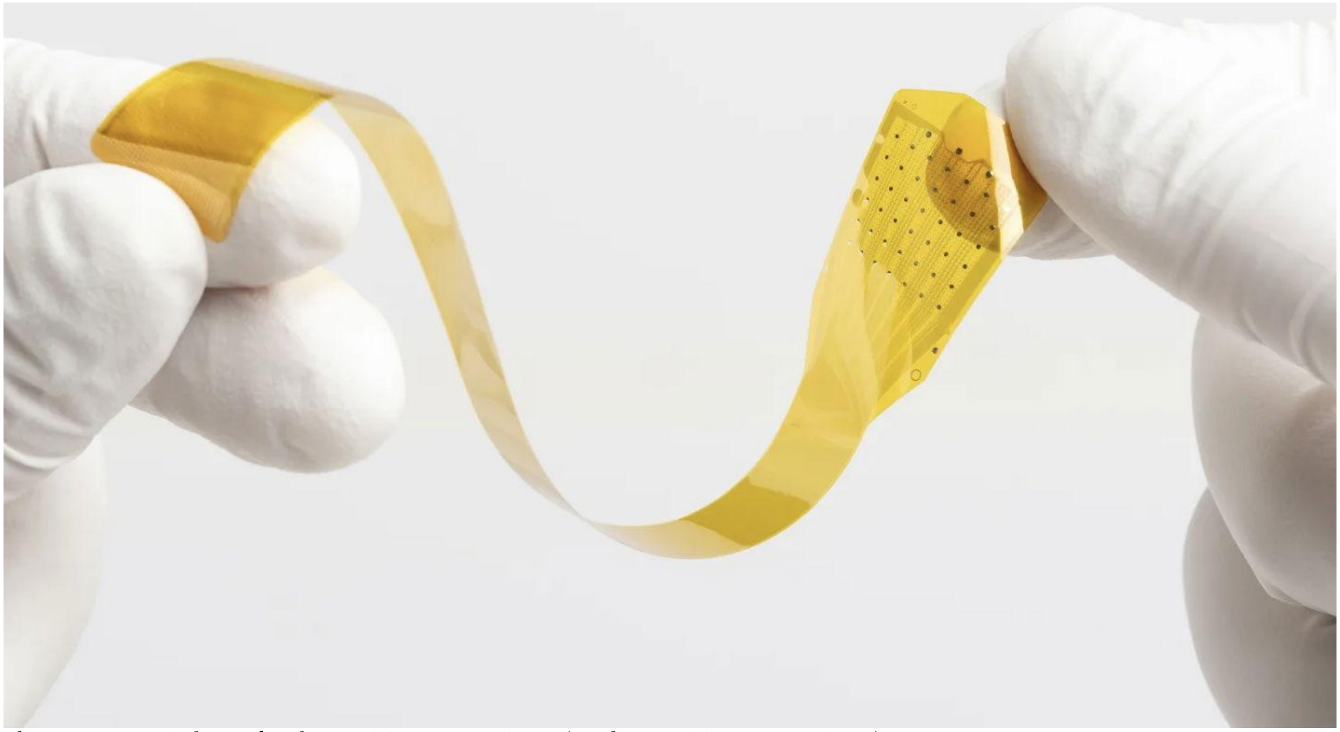
Neural activity in the thalamofrontal loop more accurately distinguished between conscious and unconscious trials than between any other task elements, including stimulus contrast, rule cues, or eye movement direction. Performance differences were significant even in near-threshold conditions where stimulus properties remained constant.

Researchers conclude that intralaminar and medial thalamic nuclei serve as origin points for the neural activity underlying human conscious perception. These high-order structures not only activate earlier than prefrontal cortex areas but also appear to initiate functional coupling that coordinates cortical activity. Thalamic signals more reliably predict subjective awareness than other cognitive features of the task, including sensory intensity or behavioral output.

These findings add direct human evidence to support theories proposing thalamic nuclei as a gateway for conscious perception. Results challenge models that assign primary responsibility for awareness to the cortex alone. By identifying specific thalamic-cortical pathways involved in perception, the study offers new insight into how transient sensory experiences rise into conscious awareness.

Clarifying the role of these subcortical networks could inform future approaches to treating disorders of consciousness and refining brain-machine interface design.

More information: Zepeng Fang et al, Human high-order thalamic nuclei gate conscious perception through the thalamofrontal loop, *Science* (2025). DOI: 10.1126/science.adr3675
Journal information: Science


The Layer 7 Cortical Interface by Precision Neuroscience (Credit: Precision Neuroscience)

PRECISION NEUROSCIENCE GAINS EDGE IN BRAIN-COMPUTER INTERFACE RACE WITH FDA CLEARANCE

APRIL 28, 2025

With the field of brain-computer interface (BCI) technologies growing increasingly competitive, Precision Neuroscience has emerged as a sigificant contender in the race to unite human minds with machines.

A four-year-old company, Precision Neuroscience announced on April 17 that its core brain implant system had received approval from the U.S. Food and Drug Administration (FDA) for commerical use and limited implantation uses. According to the company's announcement, this marks the first full regulatory clearance granted to a wireless BCI.

This milestone highlights the company's rapid technological advancement, drawing attention from rivals such as Elon Musk's

Neuralink and Synchron, backed by Amazon founder Jeff Bezos and Microsoft co-founder Bill Gates.

The FDA approval pertains to Precision's Layer 7 Cortical Interface, a sophisticated microelectrode array used to decode neural signals and translate them into commands for external technologies. The FDA's clearance allows Precision to implant the device in patients for up to 30 days—marking the first time in history a BCI system has received such approval for long-term use in a clinical setting.

"This is a foundational moment for Precision," said Dr. Benjamin Rapoport, Precision's co-founder and chief science officer. Rapoport, who also helped co-found Neuralink, left that company the following year after its founding.

The Layer 7 Cortical Interface features an ultra-thin microelectrode array—thinner than a human hair—that adheres to the brain's surface without causing damage. Resembling a strip of yellow Scotch tape, the array is composed of 1,024 electrodes designed to record, monitor, and stimulate electrical activity on the brain's surface.

The FDA approval will enable surgeons to use the system during brain surgeries to map brain signals, a crucial step in advancing BCI technology. However, this is not the company's ultimate goal for the device, but it does present an immediate opportunity to collect critical data while generating early revenue.

To date, Precision Neuroscience has temporarily implanted the Layer 7 device in 37 patients, with some cases observed at Mount Sinai Hospital in New York. Until now, the implants were used for shorter periods during ongoing brain surgeries unrelated to BCI research. With the FDA's green light, the company can now collect data over extended periods, further advancing the development of future brain-computer interface systems.

Dr. Rapoport explained that the new clearance will allow Precision to collect high-quality data, which will be pivotal as the company works toward its long-term goal: developing a brain implant system that can help paralyzed patients restore lost functions such as movement and speech.

With competition in the BCI sector intensifying, Precision Neuroscience's FDA approval could position the company at the forefront of the industry, rivaling Neuralink and other tech giants. As neurotech innovations continue to evolve, Precision's work could play a crucial role in transforming the lives of individuals with paralysis, offering them a potential pathway to regain independence and improve their quality of life.

Meanwhile, companies like Neuralink continue to perform well, even as political shifts in the U.S. have introduced new uncertainties. Since the Trump administration's return to office in January, drastic cuts to federal employees were made in February, including layoffs within the U.S. Food and Drug Administration—some of whom were connected to the review of Neuralink's technologies. This political turbulence has coincided with a growing exodus of American postgraduate and PhD students and scientists relocating to Canada and other countries worldwide.

Despite the political uncertainty impacting the broader scientific community, advancements in BCI technology are not slowing down—in fact, they appear

CREDIT: Pixabay/Melmak

MIT DEVELOPS ULTRA-THIN SENSOR SKIN THAT COULD REDEFINE NIGHT VISION AND WEARABLE TECH

·APRIL 23, 2025

An electronic sensor “skin” developed by MIT engineers—the thinnest pyroelectric material ever fabricated—could revolutionize electronics by enabling ultra-thin, flexible sensors for next-generation night vision devices and autonomous vehicles.

Pyroelectric materials generate an electrical current in response to thermal fluctuations. This 10-nanometer-thick film’s extreme thinness actually enhances its sensitivity to minute temperature changes.

A NEXT-GENERATION INFRARED SENSOR

Laboratory testing revealed that the material is highly sensitive to far-infrared heat and radiation. The film could help solve longstanding optical sensing challenges, such as creating lightweight night-vision eyewear and improving autonomous vehicle navigation under difficult conditions. Unlike current state-of-the-art infrared sensors, which require bulky cooling systems, the pyroelectric film offers greater precision without the need for cooling.

"This film considerably reduces weight and cost, making it lightweight, portable, and easier to integrate," said Xinyuan Zhang, a graduate student in MIT's Department of Materials Science and Engineering. "For example, it could be directly worn on glasses."

Beyond local biological and environmental sensing, MIT researchers envision astronomical applications for their film. In addition to developing the material, the team also created a new technique for peeling the film from its growth substrate—a process they believe could be adapted for producing other types of semiconductor films.

FABRICATING THE ELECTRONIC SKIN

Jeehwan Kim, associate professor of mechanical engineering and materials science and engineering at MIT, leads the research group focused on creating ever-thinner flexible electronics. Working alongside a team led by Professor Chang-Beom Eom at the University of Wisconsin–Madison, they aim to incorporate computing skins seamlessly into contact lenses and wearable fabrics, placing sensors and smart technologies at extremely close range. Larger applications, like bendable displays and stretchable solar cells, are also on the horizon.

Kim's team developed a novel method called "remote epitaxy." In this process, a single layer of crystalline substrate acts as the scaffold for growing new material, while an ultra-thin graphene coating—acting like Teflon on a frying pan—prevents the new material from sticking too tightly. This allows the researchers to easily peel the film away, preserving the substrate for reuse.

A SURPRISING PEEL

In their experiments, the MIT team tested various semiconductor blends before noticing that the pyroelectric material PMN-PT unexpectedly peeled away from the substrate easily, even without the graphene layer.

"It worked surprisingly well," Zhang says. "We found the peeled film is atomically smooth."

Investigating why the delicate film held together during removal, the researchers identified lead atoms as the key factor. In PMN-PT's chemical structure, lead atoms' orderly arrangement attracts their own electrons, rather than allowing them to bond strongly with the substrate—a property known as low electron affinity.

A NEW SENSOR

Capitalizing on this discovery, the researchers produced 10-nanometer-thick PMN-PT films. They then applied the films to small chips, creating a 100-pixel heat sensor.

Testing revealed the films' exceptional sensitivity to temperature changes, comparable to the best night-vision systems. Conventional night vision devices rely on photodetectors that must be cooled to prevent signal noise from distorting images. In contrast, PMN-PT sensors achieve high sensitivity without cooling, maintaining image quality while dramatically reducing device bulk and weight.

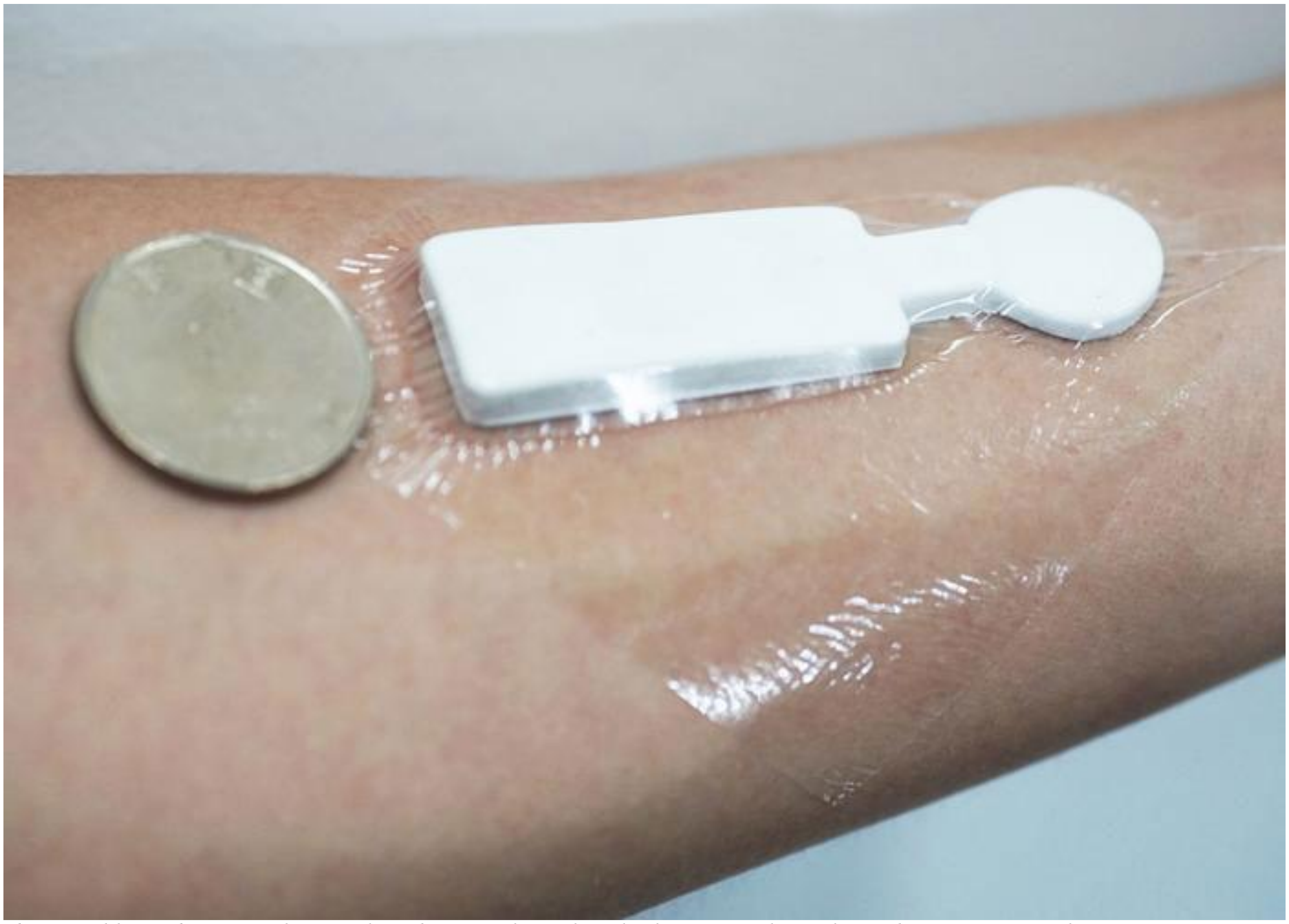
Further testing showed the film could detect wavelengths across the entire infrared spectrum, expanding its potential applications beyond night vision. The team identified other promising uses, such as helping autonomous vehicles detect pedestrians and obstacles in dark, foggy, or rainy conditions. Additional possibilities include gas sensors for environmental monitoring and thermal diagnostics to detect malfunctioning semiconductor chips through sudden heat changes.

FUTURE FILMS

Looking ahead, the team plans to adapt their peeling technique to materials that do not contain lead. They are exploring ways to modify the process by applying lead only to the growing surface.

"We envision that our ultrathin films could be made into high-performance night-vision goggles, considering its broad-spectrum infrared sensitivity at room-temperature, which allows for a lightweight design without a cooling system," Zhang says. "To turn this into a night-vision system, a functional device array should be integrated with readout circuitry. Furthermore, testing in varied environmental conditions is essential for practical applications."

The paper "Atomic Lift-off of Epitaxial Membranes for Cooling-free Infrared Detection" appeared on April 23, 2025 in *Nature.*


The wearable patch can simultaneously and accurately track multiple emotional signals. Credit: Courtesy Yangbo Yuan, Penn State.

FORGET “MOOD” RINGS, THIS INVENTION JUST IDENTIFIED HUMAN EMOTIONS WITH NEARLY 90% ACCURACY

APRIL 23, 2025

Penn State University scientists have invented a sticker that successfully identifies human emotions with nearly 90% accuracy. Designed to interpret several biological signals, including temperature and heart rate, the new sticker could help medical professionals treating people with difficulty communicating or psychiatric professionals trying to interpret and treat complex emotional conditions.

"This is a new and improved way to understand our emotions by looking at multiple body signals at once," said Huanyu "Larry" Cheng, an Associate Professor of Engineering Science and Mechanics at Penn State and lead author on the paper outlining the team's work in a statement.

THE GROWING INTERSECTION BETWEEN TECHNOLOGY AND HUMAN EMOTIONS

When novelty items like mood rings or emotion bracelets first arrived in the mid-twentieth century, they were relatively simple devices that changed color depending on changes in body temperature. While a fun distraction, these devices were far from accurate in interpreting actual human emotions.

More recently, scientists have been exploring ways to analyze and decipher individual emotional states beyond simply asking patients how they feel. Some have looked at the role that the food we eat plays in emotions, while others are exploring emotions at their source. More practical attempts to integrate technology and human emotions have included designing an app to reduce negative thoughts, using brain scans to read people's minds, or even attempts at using psychology to defend against cyberattacks.

In a new study published in *Nano Letters*, Penn State scientists have taken these approaches to a new level by measuring physical responses to interpret emotional states. Unlike previous efforts to read human emotions that relied on the electrical properties of skin or facial expressions, this approach uses several disparate inputs to create the most complete and accurate interpretation of emotional states.

"Relying only on facial expressions to understand emotions can be misleading," Cheng explained. "People often don't visibly show how they truly feel, so that's why we're combining facial expression analysis with other important physiological signals, which will ultimately lead to better mental health monitoring and support."

WIDE RANGE OF INPUTS AIDS ACCURATE EMOTION ANALYSIS

According to a statement from the research team behind the novel invention, their approach involves a set of sticker-like patches that attach directly to the skin. Made with layers of flexible metals like platinum and gold cut into wave-like shapes, the device can maintain performance and conductivity when stretched or pulled.

The device was also built with several layers of materials that can change the flow of electricity when temperatures change. Along with body temperature, the patch is equipped with a suite of sensors designed to track humidity, heart rate, and blood oxygen levels, which the researchers note "are associated with emotional states." These include hollow nanotubes made of carbon atoms that can detect humidity directly.

To complement these biometric sensors, the system also incorporates a separate patch attached directly to the face. By collecting facial expression data and analyzing it in combination with physiological data, the team says their system can "better distinguish between genuine emotions and acted ones." Notably, the team designed their device so that the sensors all act separately and are not affected by the other incorporated sensors. This design increases the chances of a more accurate emotional diagnosis.

A specialized patch collects information on human expressions to increase the accuracy of the diagnosis of emotional states. Courtesy Yangbo Yuan / Penn State

"We've engineered this device to measure these different signals independently, without them interfering with each other, providing a much clearer and more accurate picture of what's happening beneath the surface," said Libo Gao, co-corresponding author on the paper and an associate professor at Xiamen University.

Finally, along with its suite of sensors, the team equipped their emotion reading patch with a wireless interface to send data directly to the cloud for a clinician to examine for rapid evaluation. The team says the device does not collect any personal data, helping users maintain privacy.

DEVICE SUCCESSFULLY DECIPHERS EMOTIONS WITH 88.83% ACCURACY

To test their device's accuracy, the researchers enlisted eight volunteers. Each volunteer was asked to "perform" six common facial expressions depicting distinct, individual emotional states: happiness, surprise, fear, sadness, anger, and disgust. After performing each emotional state 100 times, the team fed the data into a specially programmed AI model that was specially designed to spot and interpret outward signs of human emotion.

When the team asked three additional volunteers to help confirm their work by performing the six emotions, the device could classify them with 96.28% accuracy. Still, the team wanted to see how their system would interpret actual emotions instead of performed emotions. This meant showing the same volunteers a series of video clips designed to elicit specific emotional responses.

According to the team's statement, the device accurately identified 88.83% of the actual emotional states experienced during the video clips. The device's integrated sensors confirmed this data, showing that "the psychological responses were consistent with known links between emotions and psychological reactions, such as increases in skin temperature and heart rate during surprise and anger."

DEVICE COULD FILL 'GAPS IN CARE', ALLOW FOR 'PROACTIVE SUPPORT'

Although the device is not commercially available, the team says it could be valuable in several clinical settings. For example, it could help caregivers communicate with patients who cannot talk. The device could also assist patients who are struggling with mental health issues or honesty.

"This technology has the potential to help people who are struggling with their mental health, but maybe aren't being fully honest with others or even themselves about how much they are struggling," said Yangbo Yuan, co-author on the paper and doctoral student at Penn State studying engineering science and mechanics.

"This sensor can serve a vital function in bridging gaps in access to care," Cheng added. "Given the rising stress levels in modern society, the ability to monitor emotions can provide early indicators of debilitating conditions and allow for proactive support."

The team also believes their device could help bridge "cultural or social gaps" that make it difficult for caregivers to interpret their emotional state. The team also sees potential for preventative care. According to Cheng, by keeping track of biological signals associated with human emotions, "it could be possible to detect problems like anxiety or depression earlier in their progression."

"While still in the research and development phase, this device is a significant step forward in our ability to monitor and understand human emotions, potentially paving the way for more proactive and personalized approaches to mental health care," Cheng said.

THE "HOLY GRAIL" OF NEUROSCIENCE? RESEARCHERS CREATE STUNNINGLY ACCURATE DIGITAL TWIN OF THE BRAIN

·APRIL 15, 2025

In a breakthrough that could revolutionize neuroscience, researchers have harnessed the power of artificial intelligence to create a highly accurate "digital twin" of the mouse brain. This advanced AI model can predict how neurons respond to entirely new visual stimuli—something no previous model has accomplished with such precision.

Recently published in *Nature*, the study—led by scientists from Baylor College of Medicine, Stanford University, and the Allen Institute for Brain Science—introduces a sophisticated artificial neural network called a "foundation model."

The model replicates brain activity and mirrors the intricate structural details of neural circuits, offering a powerful new tool for exploring the brain's inner workings.

Much like how ChatGPT and other large language models transformed natural language processing, this brain model could reshape how we study perception, behavior, or even consciousness.

"If you build a model of the brain and it's very accurate, that means you can do a lot more experiments," Stanford professor of ophthalmology and senior author of the study, Dr. Andreas Tolias, explained in a press release. "We're trying to open the black box, so to speak, to understand the brain at the level of individual neurons or populations of neurons and how they work together to encode information."

A BRAIN DIGITAL TWIN THAT THINKS AHEAD

For decades, decoding the brain's language has been one of science's most enduring puzzles. Traditional neural network models, often trained to respond to specific data sets like object recognition tasks or motion detection, performed well but only within their comfort zones. These models struggle once unfamiliar data is introduced, such as new types of images or stimuli.

Inspired by the power of foundation models in AI—large-scale models trained on massive datasets that generalize remarkably well to new domains—neuroscientists set out to create something similar for the brain.

They recorded real-time neural responses in 14 awake mice as the animals watched natural videos and interacted with their environment. "It's very hard to sample a realistic movie for mice because nobody makes Hollywood movies for mice," Dr. Tolias said. "[However] mice like movement, which strongly activates their visual system, so we showed them movies that have a lot of action."

These recordings captured visual stimuli, behavior (like eye movement and pupil dilation), and contextual variables across six visual brain areas. Over 900 minutes of data from the mice watching clips of action movies, such as *Mad Max*, were fed into an artificial neural network (ANN).

The result was a four-part model: a "perspective" module to account for how a mouse's eye sees a stimulus, a "modulation" module to interpret behavioral signals, a "core" that processes the bulk of the sensory data, and a "readout" that translates that data into predictions of neural activity. Trained on just eight mice, the model proved startlingly robust—accurately predicting brain responses in new mice and across novel stimulus types it had never seen before.

The crown jewel of this ANN is what researchers call the "foundation core." Once trained, this shared internal representation of visual processing could be "transferred" to new individual mice with minimal additional data—sometimes as little as four minutes of new recordings. This dramatically reduced the amount of real-world data needed to accurately model a new brain.

Compared to previous leading models, the new foundation model achieved a 25–46% improvement in predictive accuracy, even in notoriously complex higher-order visual areas of the brain. These performance gains represent a blueprint for developing increasingly accurate models of the brain that can adapt quickly to new data without starting from scratch.

Remarkably, the model didn't stop at predicting how neurons would fire. It also inferred their physical characteristics—like where they sit in the brain and what kind of neuron they are.

In another major leap for neuroscience, researchers with the MICrONS project recently unveiled the most detailed functional map of the brain to date, offering unprecedented insight into how neurons connect, interact, and communicate. This feat was once considered "impossible."

Using data from the MICrONS project, researchers applied their model to more than 70,000 neurons. The model accurately predicted anatomical cell types, dendritic structures, and even synaptic connectivity patterns despite never having been trained on anatomical data.

This suggests that the "functional barcodes" generated by the model—essentially, how a neuron processes visual information—can be used as fingerprints to reveal a cell's type and structure.

UNLIMITED POTENTIAL, ZERO INVASIVENESS WITH DIGITAL TWINS

A key advantage of creating a digital twin of the brain is its scalability. Because the model can simulate neural responses inside a computer, researchers can now run unlimited experiments that would be time-consuming, invasive, or even impossible to perform on living brains.

For example, researchers tested how digital brains responded to classical vision experiments—like moving dots, Gabor patches, or flashing lights—and found that the digital neurons exhibited the same orientation or spatial selectivity as their real counterparts. In one test, simulated neurons matched the actual preferred orientation of live neurons within just 4 degrees, an extraordinary degree of precision.

TOWARD A UNIFIED MODEL OF THE BRAIN

By leveraging similarities between brains, rather than treating each one as a separate puzzle, researchers can now model shared cognitive features while still accounting for individual quirks.

Additionally, what makes this recent breakthrough stand out isn't just the technical prowess—it's the philosophical leap. Foundation models, by their nature, don't just memorize; they internalize general principles. The hope is that a similar approach in neuroscience could eventually uncover a universal set of rules that governs how all brains process information.

By uncovering a shared set of rules that govern how neurons encode, process, and transmit information, scientists could be on the verge of establishing foundational laws of neuroscience, akin to the laws of physics that govern the natural world.

Just as equations like Newton's laws or Einstein's theories of relativity provide a framework for understanding motion and energy across the universe, a universal neural code could offer a unifying theory for how brains function across species, individuals, and contexts.

Such a discovery would revolutionize our understanding of cognition and behavior and lay the groundwork for predictive, standardized models of brain activity, ushering in a new era of neuroscience.

"Our present foundation model is just the beginning, as it only models parts of the mouse visual system under passive viewing conditions," researchers wrote. "As we accumulate more diverse multimodal data—encompassing sensory inputs, behaviors, and neural activity across various scales, modalities, and species, foundation neuroscience models will enable us to decipher the neural code of natural intelligence, providing unprecedented insights into the fundamental principles of the brain."

NEXT STEPS AND BROADER IMPLICATIONS

The success of this model raises significant questions about the future of neuroscience—and the ethical and philosophical implications of simulating brains with such fidelity.

Could similar models one day simulate the human brain? Could they lead to better brain-computer interfaces, more accurate diagnoses for neurological diseases, or even a deeper understanding of consciousness?

The researchers caution that we're not there yet. Their digital brain twin currently applies only to mice's visual cortex under passive viewing conditions. But the groundwork has been laid for a much broader project.

Ultimately, in the same way that large language models unlocked new capabilities in artificial intelligence, this digital twin of the brain could unlock new frontiers in biology, medicine, and cognitive science. And in doing so, it brings us a step closer to answering the enduring mysteries of the brain.

"In many ways, the seed of intelligence is the ability to generalize robustly," Dr. Tolias said. "The ultimate goal — the 'holy grail' — is to generalize to scenarios outside your training distribution."

"Eventually, I believe it will be possible to build digital twins of at least parts of the human brain. This is just the tip of the iceberg."

IARPA RESEARCH ACHIEVES THE IMPOSSIBLE IN NEW BREAKTHROUGH REVEALING THE BRAIN'S BIGGEST MYSTERIES

APRIL 14, 2025

In a scientific feat once deemed "impossible," researchers have mapped the most detailed wiring diagram and functional map of the brain to date, revealing a never-before-seen level of intricacy in how neurons connect and communicate.

In a groundbreaking study funded by the U.S. Intelligence Advanced Research Projects Activity (IARPA), scientists from the MICrONS

Consortium harnessed advanced imaging and computational tools to uncover the intricate workings of the mouse visual cortex.

The breakthrough, recently published in *Nature*, represents a technical triumph and a transformative leap for neuroscience that could reshape our understanding of cognition, behavior, and brain disorders.

“The MICrONS advances published in this special issue of Nature are a watershed moment for neuroscience, comparable to the Human Genome Project in their transformative potential,” Dr. David A. Markowitz, Ph.D., former IARPA program manager who coordinated this work, said in a release.

“IARPA’s moonshot investment in the MICrONS program has shattered previous technological limitations, creating the first platform to study the relationship between neural structure and function at scales necessary to understand intelligence. This achievement validates our focused research approach and sets the stage for future scaling to the whole brain level.”

In 1979, Nobel laureate Dr. Francis Crick famously declared, “It is no use asking for the impossible, such as, say, the exact wiring diagram for a cubic millimeter of brain tissue and the way all its neurons are firing.” However, today, that impossible dream has become a reality.

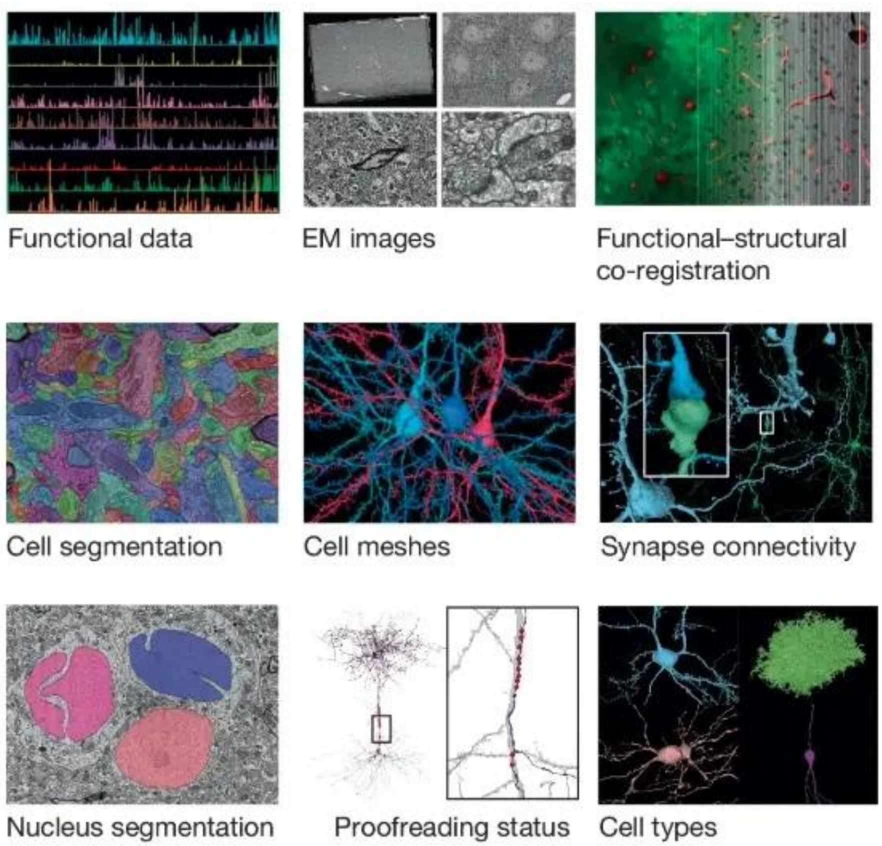
Using a combination of dense calcium imaging and serial-section electron microscopy (EM), scientists analyzed a cubic millimeter of mouse visual cortex. The result was a high-resolution dataset detailing over 200,000 cells and over 500 million synapses, with functional responses recorded from approximately 75,000 neurons in a living mouse. The achievement represents not just a leap in scale but a fusion of form and function, linking what neurons look like with what they do.

What sets the MICrONS project apart is its unprecedented integration of neuronal function and connectivity. The researchers were able to measure the responses of individual neurons to a wide range of visual stimuli, from natural scenes to artificially generated patterns. These responses were then co-registered with a dense 3D reconstruction of synaptic connections within the same brain volume.

The mapping was done across four areas of the mouse visual cortex—VISp, VISlm, VISrl, and VISal—covering all cortical layers except for the extremes of Layer 1. This allowed scientists to observe how neurons connect not only within an area but also across regions, uncovering feedforward and feedback loops crucial for visual processing.

The dataset includes pyramidal neurons, inhibitory neurons from many known classes (e.g., basket and chandelier cells), non-neuronal cells like astrocytes and microglia, and vasculature.

Each component is rendered in rich detail and publicly available through an open-access online platform, MICrONS Explorer.



Example of the types of data resources made publicly available by the MICrONS project (Image Source: the MICrONS project/Nature)

As Dr. Crick famously implied, creating this comprehensive map of neural connections in the brain was no trivial task. The tissue was sliced into nearly 28,000 serial sections, each 40 nanometers thick, and imaged over six months using five customized automated transmission electron microscopes. The resulting 2-petabyte dataset was stitched with advanced convolutional neural networks, identifying and tracing neurons and synapses with remarkable precision.

Beyond its technical novelty, the study revealed fundamental insights into how the brain organizes information. For instance, it confirmed the existence of a “like-to-like” connectivity principle, where neurons with similar functional properties tend to form stronger and more frequent connections. This finding helps explain how the brain efficiently processes sensory information.

Other discoveries include novel forms of neuronal invariance (where neurons respond consistently to the same stimulus despite changes in context) and patterns of connectivity that vary across cortical layers and cell types.

The data also helped define new computational principles underlying inter-areal communication, suggesting how visual information is integrated across different brain regions.

“Inside that tiny speck is an entire architecture like an exquisite forest,” Dr. Clay Reid, a member of the IARPA MICrONS project and senior investigator at the Allen Institute, explained. “It has all sorts of rules of connections that we knew from various parts of neuroscience, and within the reconstruction itself, we can test the old theories and hope to find new things that no one has ever seen before.”

Findings from this study hold transformative potential for medicine, artificial intelligence (AI), and beyond.

In neuroscience, understanding brain wiring at this scale can lead to better models of brain function, ultimately guiding treatments for disorders like epilepsy, schizophrenia, and autism, which are thought to stem from connectivity dysfunctions.

By providing a “ground truth” dataset, the IARPA MICrONS project enables more accurate simulations of brain activity, allowing researchers to test previously speculative hypotheses.

This breakthrough is more than just a detailed map of brain activity. Rather, it serves as a resource that will help answer long-standing questions about how the brain works and perhaps even how it goes wrong in disease.

In AI, the dataset could inspire the next generation of machine learning algorithms. Neural networks, after all, were inspired by the brain—but until now, they lacked detailed biological data for their design. Computer scientists can build more efficient and robust systems by studying how real neurons connect and process information.

“If you have a broken radio and you have the circuit diagram, you’ll be in a better position to fix it.” Dr. Nuno da Costa, an associate investigator at the Allen Institute, explained. “We are describing a kind of Google map or blueprint of this grain of sand. In the future, we can use this to compare the brain wiring in a healthy mouse to the brain wiring in a model of disease.”

The MICrONS project has made its entire dataset available for public use. With tools like the Neuroglancer visualization platform and cloud-based APIs, professional and amateur scientists can explore and analyze the data without downloading terabytes of information.

Moreover, the researchers developed new tools to facilitate large-scale proofreading and analysis of neuron reconstructions, including the ChunkedGraph system and the NEURD error correction workflow. These innovations dramatically improve the speed and accuracy of working with such massive datasets.

Despite the achievement, challenges still remain. Proofreading and annotating such massive volumes of data is a labor-intensive process. While automated systems are improving, human oversight is essential for ensuring accuracy, especially in complex or ambiguous cases.

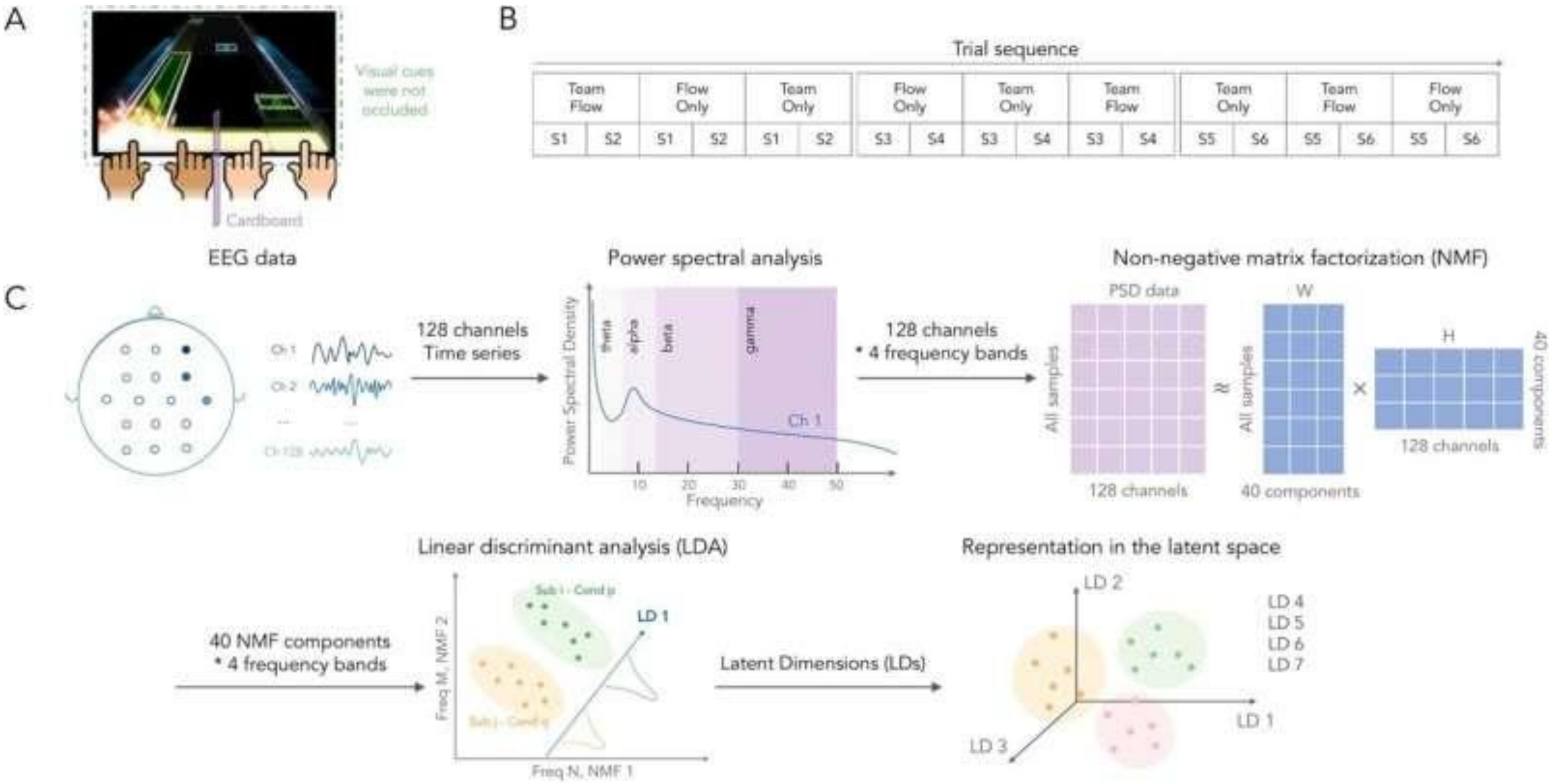
The IARPA MICrONS dataset stands as a powerful testament to what a multidisciplinary approach can achieve, transforming what once seemed "impossible" into reality. Researchers behind the project see this accomplishment not as an endpoint but as the foundation for a new era of scientific discovery.

"This is the future in many ways," Dr. Andreas Tolias, one of the IARPA project's lead scientists at Baylor College of Medicine and Stanford University, said. "MICrONS will stand as a landmark where we build brain foundation models that span many levels of analysis, beginning from the behavioral level to the representational level of neural activity and even to the molecular level."

APRIL 14, 2025

On the same wavelength: Neural 'fingerprints' indicate deep focus flow states in teams

by Lori Dajose, California Institute of Technology



Data acquisition and analysis pipeline. Credit: *Scientific Reports* (2025). DOI: 10.1038/s41598-025-95916-9

Have you ever been so laser-focused on a task—playing a video game, reading an engrossing book, and so on—that when you look up, hours have suddenly gone by? This is commonly referred to as flow state: a state of absorbed concentration and a distorted sense of time. Studies have shown that working in the flow state has a positive impact on happiness and productivity.

A new Caltech-led study examines the phenomenon of "team flow," where individuals work in a flow state with others. Like a fingerprint, the electrical activity of the brain looks different from person to person, including during a flow state (team or solo).

By measuring the brainwaves of volunteers as they played a collaborative video game, the researchers discovered that people whose neural patterns or "neural traits" looked similar were able to more easily achieve a team flow state together. The research is described in a paper published in the journal *Scientific Reports*.

The study was a collaboration between the Caltech laboratory of Shinsuke Shimojo, the Gertrude Baltimore Professor of Experimental Psychology, and the laboratory of Mohammad Shehata at Toyohashi University of Technology in Japan. Shehata is also a visiting associate in biology and biological engineering at Caltech.

"The concept of flow state is very grounded in positive psychology," Shehata says. "It's good for mental health and productivity without leading to burnout. Many people have experienced this 'vibe,' and now we are trying to characterize it with psychophysics and neuroscience."

The research built on a previous study that examined flow state when pairs of participants collaborated to play a video game. The game requires players to press keys with precise timing, as if playing a piece of music, similar to the popular game Guitar Hero. To measure team flow, the participants had to collaborate on the game, each responsible for playing some of the keys.

The researchers measured the participants' brain activity using an electroencephalogram (EEG), a noninvasive method using electrodes applied to the head. While the participants were playing the game in a closed room, the researchers would knock on the door. A person in a real flow state would be able to ignore the distractions.

Then, each person's EEG readings for team, solo, and non-flow state were mapped onto a multidimensional space. The team found that the closer two participants' readings were in this space, the more likely they would enter into team flow when working together.

Importantly, a person's EEG reading is different depending on the task at hand. For example, while two participants may be neurally far apart when doing a rhythm game—that is, not in a team flow state—they may be able to flow together well during a different task, such as solving math problem or playing a sport.

"There are huge potential applications for this work," Shehata says. "It can be used to build highly compatible teams with great performance, for example, on long space missions."

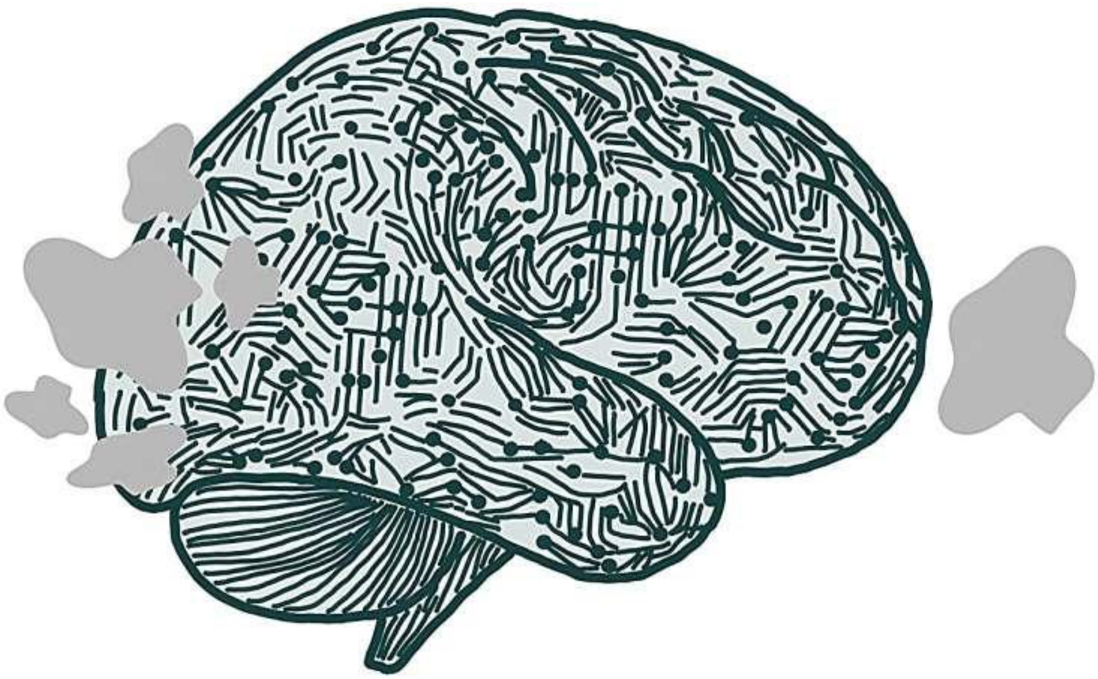
Shimojo adds, "Our goal is to continue to work on understanding the neural signatures of the team flow state so that we can ultimately predict from brain activity profiling who would be likely to flow well together in a team."

More information: Qianying Wu et al, A hierarchical trait and state model for decoding dyadic social interactions, *Scientific Reports* (2025). DOI: 10.1038/s41598-025-95916-9
Journal information: Scientific Reports
Provided by California Institute of Technology

APRIL 15, 2025
APRIL 19, 2025

Seeing with purpose: Visual cortex tunes perception to match current objectives

by Grant Currin, Columbia University School of Engineering and Applied Science



Early visual areas in the brain adapt their representations of the same visual stimulus depending on what task we're trying to perform. Credit: Rungratsameetaweemana lab/Columbia Engineering

When you see a bag of carrots at the grocery store, does your mind go to potatoes and parsnips or buffalo wings and celery?

It depends, of course, on whether you're making a hearty winter stew or getting ready to watch the Super Bowl.

Most scientists agree that categorizing an object—like thinking of a carrot as either a root vegetable or a party snack—is the job of the prefrontal cortex, the brain region responsible for reasoning and other high-level functions that make us smart and social. In that account, the eyes and visual regions of the brain are kind of like a security camera collecting data and processing it in a standardized way before passing it off for analysis.

However, a new study led by biomedical engineer and neuroscientist Nuttida Rungratsameetaweemana, an assistant professor at Columbia Engineering, shows that the brain's visual regions play an *active* role in making sense of information. Crucially, the way it interprets the information depends on what the rest of the brain is working on.

If it's Super Bowl Sunday, the visual system sees those carrots on a veggie tray before the prefrontal cortex knows they exist.

Published April 11 in *Nature Communications*, the study provides some of the clearest evidence yet that early sensory systems play a role in decision-making—and that they adapt in real time. It also points to new approaches for designing AI systems that can adapt to new or unexpected situations.

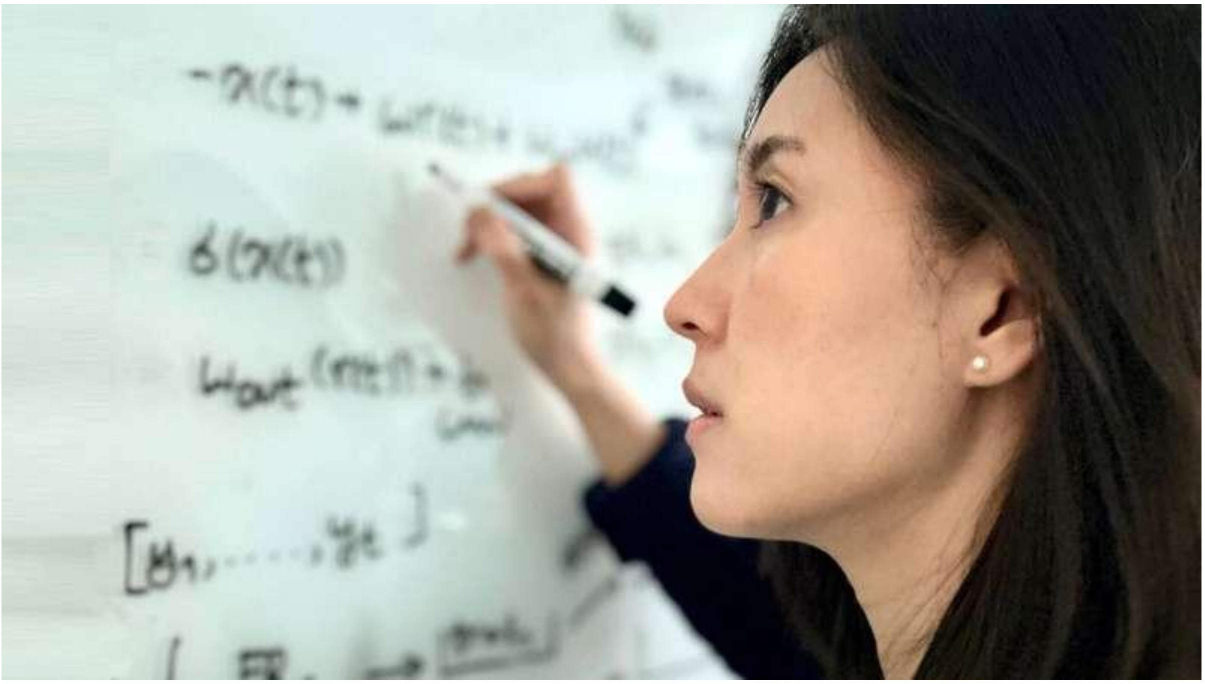
We sat down with Rungratsameetaweemana to learn more about the research.

What's exciting about this new study?

Our findings challenge the traditional view that early sensory areas in the brain are simply "looking" or "recording" visual input. In fact, the human brain's visual system actively reshapes how it represents the exact same object depending on what you're trying to do. Even in visual areas that are very close to raw information that enters the eyes, the brain has the flexibility to tune its interpretation and responses based on the current task. It gives us a new way to think about flexibility in the brain and opens up ideas for how to potentially build more adaptive AI systems modeled after these neural strategies.

How did you come to this surprising conclusion?

Most previous work looked at how people learn categories over time, but this study zooms in on the flexibility piece: How does the brain rapidly switch between different ways of organizing the same visual information?



Nuttida Rungratsameetaweemana, assistant professor of biomedical engineering. Credit: Rungratsameetaweemana lab/Columbia Engineering

What were your experiments like?

We used functional magnetic resonance imaging (fMRI) to observe people's brain activity while they put shapes in different categories. The twist was that the "rules" for categorizing the shapes kept changing. This let us determine whether the visual cortex was changing how it represented the shapes depending on how we had defined the categories.

We analyzed the data using computational machine learning tools, including multivariate classifiers. These tools allow us to examine patterns of brain activation in response to different shape images, and measure how clearly the brain distinguishes shapes in different categories. We saw that the brain responds differently depending on what categories our participants were sorting the shapes into.

What did you see in the data from these experiments?

Activity in the visual system—including the primary and secondary visual cortices, which deal with data straight from the eyes—changed with practically every task. They reorganized their activity depending on which decision rules people were using, which was shown by the brain activation patterns becoming more distinctive when a shape was near the gray area between categories. Those were the most difficult shapes to tell apart, so it's exactly when extra processing would be most helpful.

We could actually see clearer neural patterns in the fMRI data in cases when people did a better job on the tasks. That suggests the visual cortex may directly help us solve flexible categorization tasks.

What are the implications of these findings?

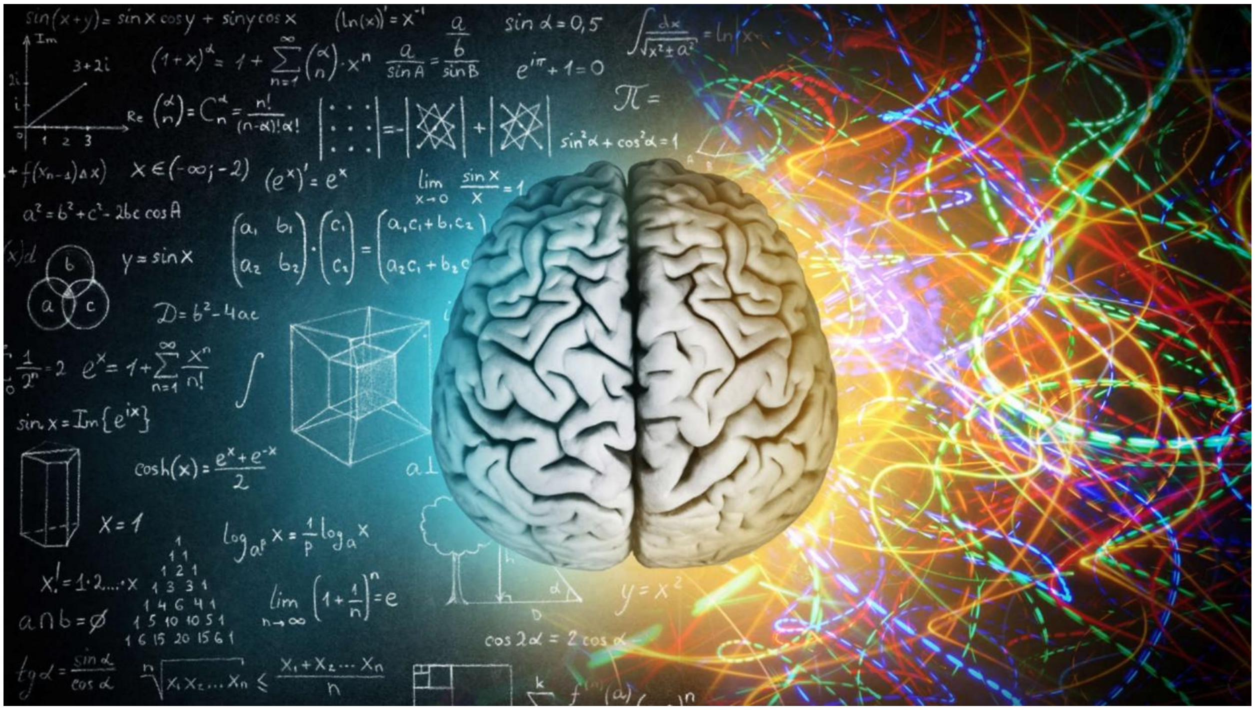
Flexible cognition is a hallmark of human cognition, and even state-of-the-art AI systems currently still struggle with flexible task performance. Our results may contribute to designing AI systems that can better adapt to new situations. The results may also contribute to understanding how cognitive flexibility might break down in conditions like ADHD or other cognitive disorders. It's also a reminder of how remarkable and efficient our brains are, even at the earliest stages of processing.

What's next for this line of research?

We're pushing the neuroscience further by studying how flexible coding works at the level of neural circuits. With fMRI, we were looking at large populations of neurons. In a new follow-up study, we are investigating the circuit mechanisms of flexible coding by recording neurological activity inside the skull. This lets us ask how individual neurons and neuronal circuits in the human brain support flexible, goal-directed behavior.

We're also starting to explore how these ideas might be useful for artificial systems. Humans are really good at adapting to new goals, even when the rules change, but current AI systems often struggle with that kind of flexibility. We're hoping that what we're learning from the human brain can help us design models that adapt more fluidly, not just to new inputs, but to new *contexts*.

More information: Margaret M. Henderson et al, Dynamic categorization rules alter representations in human visual cortex, *Nature Communications* (2025). DOI: 10.1038/s41467-025-58707-4
Journal information: Nature Communications
Provided by Columbia University School of Engineering and Applied Science



The brain’s inability to process multiple trains of thought in parallel

The human brain, often hailed as nature’s most powerful computer, is surprisingly slow when it comes to handling information. While our senses gather a mountain of data every second, our actual thoughts crawl along at a far slower pace.

Every moment, your body absorbs around a billion bits of sensory data—from sights and sounds to touch and temperature. But only about 10 of those bits make it into your conscious mind each second. That’s less than what a pocket calculator processes, and light-years behind the speed of digital devices.

Racing Minds, Hidden Limits

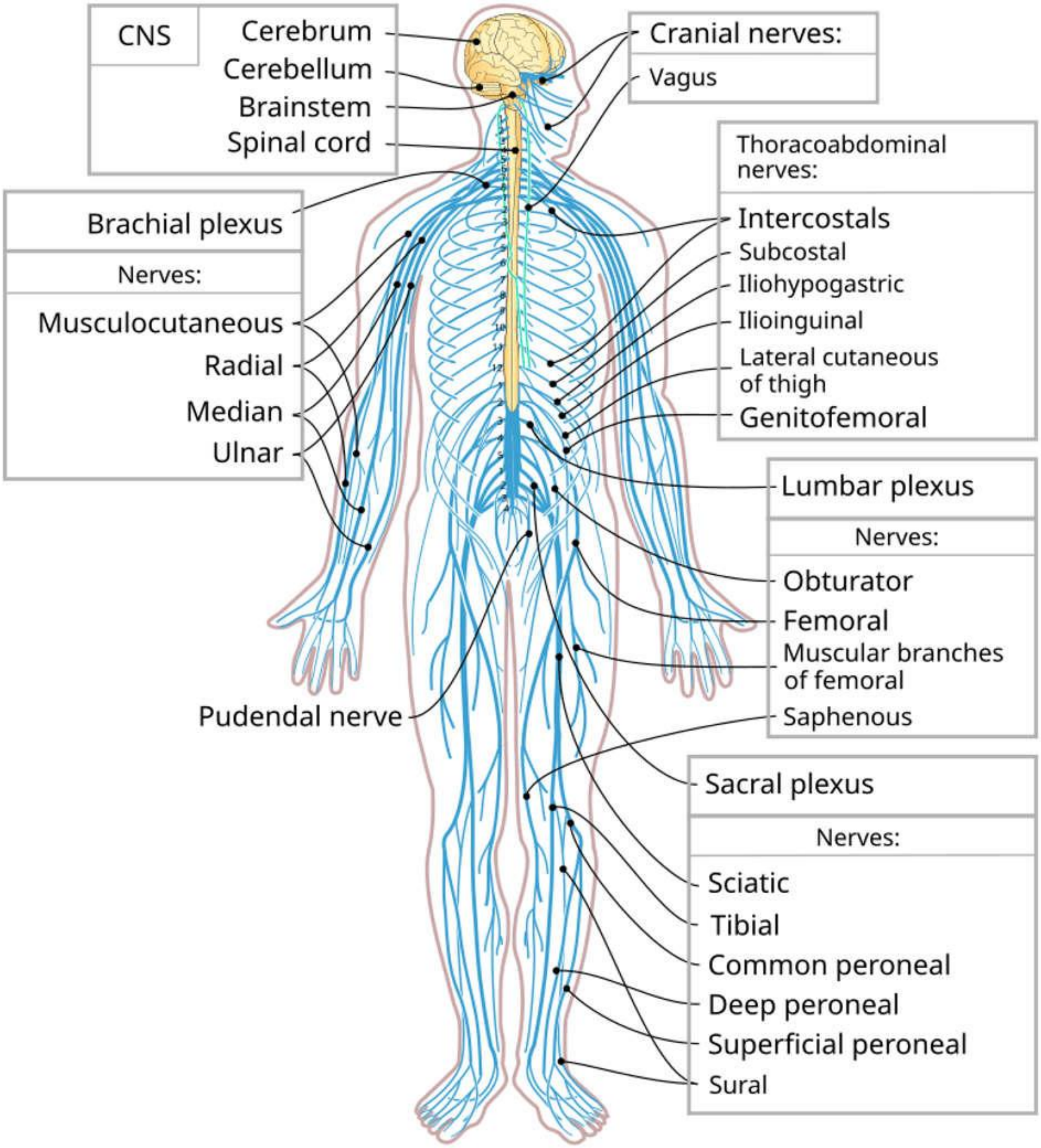
A recent study led by Jieyu Zheng at the California Institute of Technology (Caltech) dove deep into this mystery. By applying information theory to decades of research on human cognition, the team examined how data flows from the senses to conscious awareness.

They discovered a striking bottleneck. The body’s peripheral nervous system works with incredible speed, collecting sensory input from the environment almost instantly. Yet the brain reduces this torrent to just 10 bits per second—barely enough to form a complete sentence in that time.

Markus Meister on the brain's processing speed

“This is an extremely low number,” said Markus Meister, a senior researcher on the study. “Every moment, we extract just 10 bits from the trillion that our senses take in, using those 10 to perceive the world and make decisions.”

For context, a typical Wi-Fi connection transfers around 50 million bits per second. Even individual neurons are capable of transmitting far more than 10 bits each second. Yet collectively, the brain chooses to run at this low speed, revealing a puzzling contrast between its architecture and its output.



Evolutionary Constraints and Neural Architecture

Researchers speculate that evolutionary history might provide some answers. The earliest nervous systems likely evolved to support navigation, enabling organisms to move toward food and away from predators. This evolutionary path could explain why modern human thought resembles a form of navigation—moving through a conceptual space one idea at a time.

In their paper, Zheng and Meister suggest that this sequential processing is embedded in the brain's architecture. "Human thinking can be seen as a form of navigation through a space of abstract concepts," they write. The brain’s preference for linear thought aligns with its historical role in navigating physical spaces.

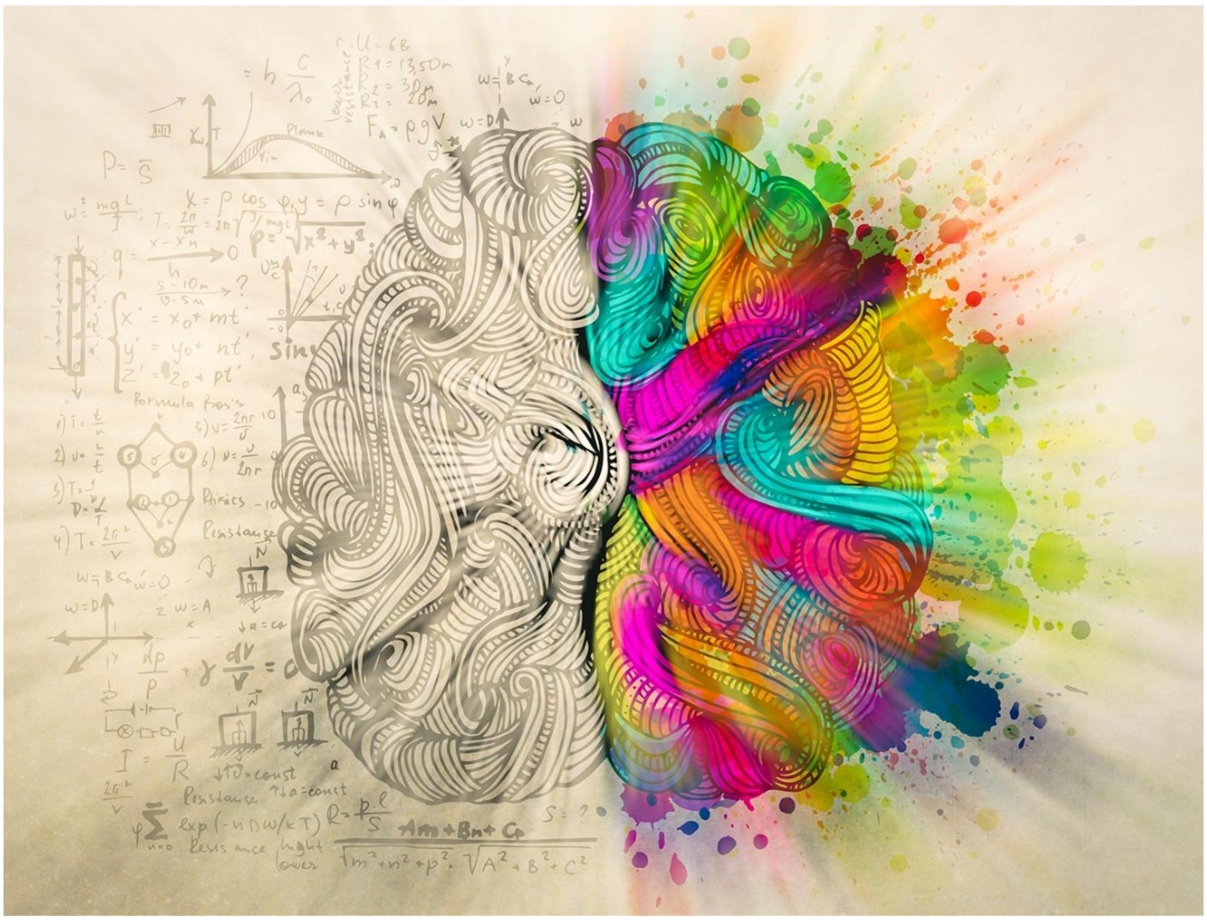
Device/Process	Approximate Processing Speed	Notes
Human Conscious Thought	10 bps	This is the rate at which we can consciously focus on and process information, as found by Caltech research.
Human Sensory Input	1 billion bps	Our senses (sight, touch, etc.) gather information at a much faster rate, but most is filtered out before reaching conscious thought.
Early Microprocessor (e.g., Intel 4004)	~100 kHz (kilohertz)	This translates to roughly 100,000 operations per second.
Modern Smartphone CPU	~2-3 GHz (gigahertz)	This equates to 2-3 billion operations per second.
Wi-Fi Connection	~50-100 Mbps (megabits per second)	This is the rate of data transfer over a wireless network.

Comparative assessment of the brain's processing speed

This slow speed of thought has significant implications for neuroscience and future technology. For instance, tech visionaries have proposed direct brain-computer interfaces to accelerate communication. However, the study’s findings suggest that such interfaces would still operate at the brain’s intrinsic limit of 10 bits per second.

This bottleneck might explain why human behavior, from playing chess to solving puzzles, involves deliberate, sequential steps. Even a chess player envisioning potential moves can only process one sequence at a time.

The neuroscience of meditation



For thousands of years, there was no way of testing scientifically whether meditation really worked. It was a purely internal experience discovered and verified by each new practitioner within their own mind. In the last few decades, new technologies have allowed us to objectively measure some of the effects of meditation. We’re far from a complete understanding, but early findings are fascinating.

At the same time there has been a revolution in the field of neuroscience with the discovery that the brain is not hardwired and fixed, even in adulthood. It is constantly changing throughout a person’s life.

Everything we do changes the brain in some way. When we practice a skill, the brain regions we use actually grow bigger, and when we don’t use parts of our brain, these regions shrink. This is what scientists call neuroplasticity.

All this adds up to the tantalizing question: How does meditation change the physical structure of the brain? Scientists are just beginning to answer this question, but we’ve already unearthed some pretty cool answers.

1. Increased Inter-Connectivity

In neuroscience these days, there is a lot of focus on how different brain areas do different things. These functional units of the brain, made up of grey matter, are like little modules, each doing its own special task, such as speech, memory, vision, or movement. Yet, in order for the brain to work as an integrated whole, the different brain regions need to send and receive information to and from each other. This is done through the brain's white matter. Think of white matter as being like fibre optic cables connecting the various modules—the brain's version of the internet.

One of the most intriguing findings that emerges from brain research is that meditation increases the amount of white matter in the brain. Unlike most skills, practicing meditation doesn't just train a few specific brain areas. **It develops the channels of communication between them.**[1]

The corpus callosum is a huge bundle of white matter fibres that connect the right and left halves of your brain. Without this connection, the left side of your body wouldn't know what was going on in the right side! Two studies found that after just 4-weeks of mindfulness training, the corpus callosum and other white matter structures in the brain had grown physically larger.[2] These studies also found increased white matter density in the sagittal stratum and corona radiata linked to improved mood among participants.[3]

There's another white matter structure that is consistently found to be larger in meditators. The superior longitudinal fasciculus bridges the front of your brain to the back, connecting attention and reflective thinking with basic body sensation.[4]

These increases in white matter enable better communication between different parts of the brain. **This could help explain how meditation increases our ability to regulate intense emotions and stress.** It might also reveal why long-term meditators start to perceive all of reality as one great interconnected whole.

2. Younger Brain Age

As we age our brains lose mass, literally shrinking inside our skulls. The brain of the average 50 year old is smaller than that of the average 20 year old. But **one study that compared the brains of meditators with non-meditators by age found that cortical thickness of 40-50 year old meditators was the same as that of non-meditators aged 20-30**.[5] The brains of meditators seem to maintain their overall mass, and on average they appear to be 7 years younger than those of non-meditators.

In addition to this overall effect, meditation leads to increases in grey matter in key brain regions. For example, meditators have increased volume in brain areas linked with attention, sensory awareness, global body awareness, and visual processing.[6] This fits with the logic of neuroplasticity. The more we use certain abilities, the larger the brain structures related to those abilities become.

3. Calming the Brain

Many of us know that meditation helps regulate stress, but until recently scientists didn't know why. Some sceptics see meditation as just a glorified form of relaxation. But an increasing amount of evidence is showing that practicing meditation causes physical changes in specific parts of the brain that govern the stress response.

One clear indicator of this is the finding that the amygdala is smaller in meditators than non-meditators.[7] **The amygdala works like a trigger to fire off the body's fight or flight response. A smaller amygdala might indicate a reduced tendency to freak out in the face of stressful situations**.

But could it be that people who are drawn to meditation might have smaller amygdalas to begin with? Could naturally calm people like to meditate, rather than meditation making them calmer? A few MRI studies have directly addressed this question by scanning the brains of non-meditators and then teaching them to meditate for 8-weeks. Afterwards, they scanned participants' brains again and found that the amygdala got noticeably smaller.[8]

Of course, the shrinking amygdala is only one part of the story. There is also evidence that meditation enlarges several brain areas responsible for regulating emotion. For example, meditators have a larger than normal lower region of the hippocampus, an area shown to act like a break to stop the release of stress hormones.[9]

4. Higher Pain Threshold

As a kid reading Batman comics, I loved the idea that his super meditation skills allowed him to shrug off pain. Well, turns out that's partly true (although much less dramatic). Scientists hooked up serious Zen meditators as well as non-meditators to a device that produced heat close to their skin.[10] The labcoats upped the temperature slowly until the participants cried uncle (don't worry, nobody was harmed). **Sure enough, the bad-ass Zen practitioners were less sensitive to pain even though they weren't meditating during the experiment**.

Looking at the participant's brain scans, researchers found that the dorsal anterior cingulate of the meditators was thicker. This increased thickness was correlated with the reduced sensitivity to pain. We know from other studies that this area of the brain is central to the emotional response to pain. So perhaps the greater size of this region allowed the meditators to tolerate a higher temperature by unconsciously regulating their response to the painful stimulus.

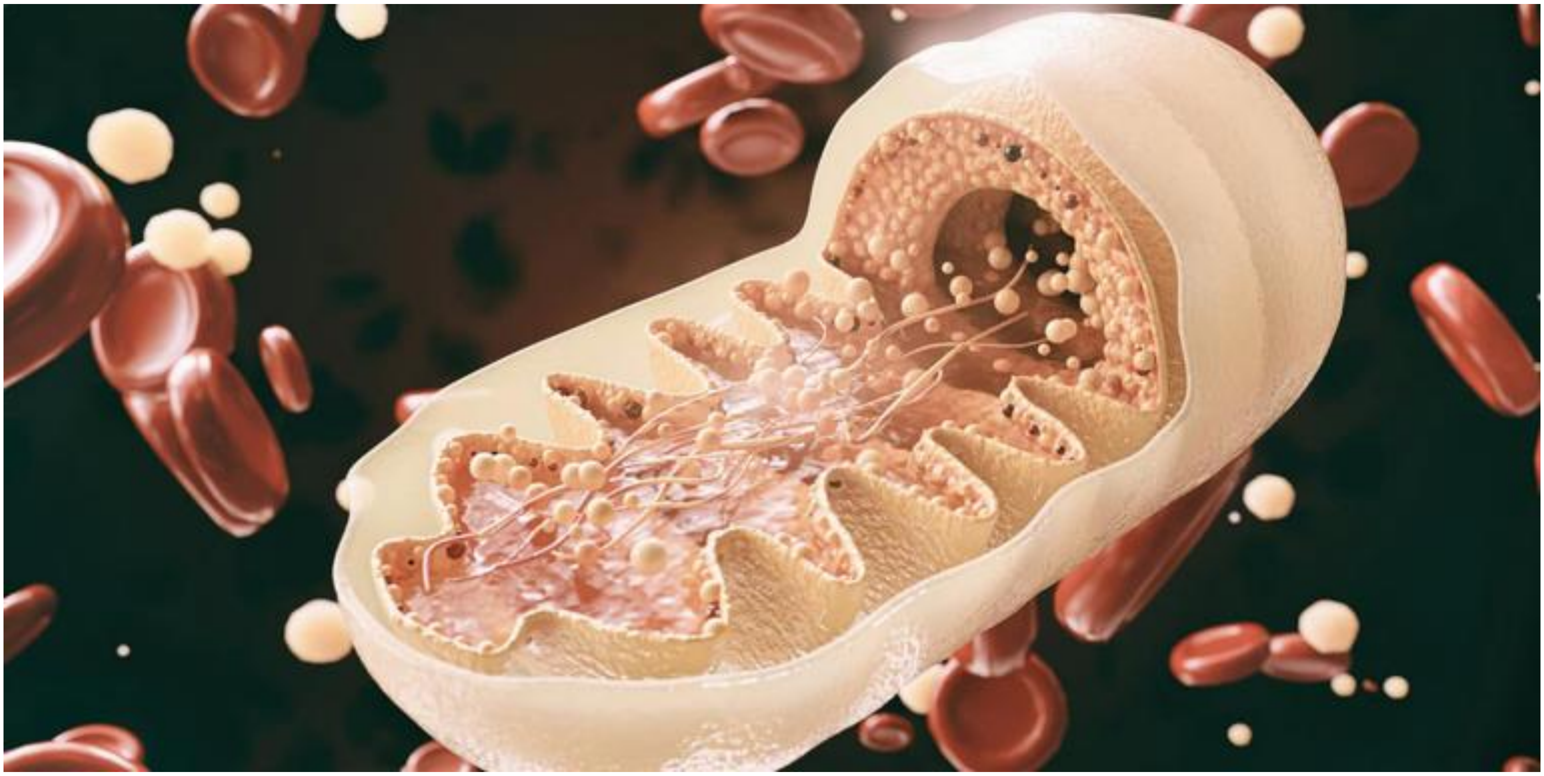
5. Groovy Brain Waves

To detect rapid changes in brain activity, scientists use EEG sensors – those little scalp electrodes that look like a cyborg's shower cap. EEG allows scientists to detect rapid electrical fluctuations called brain waves. These are classified according to the number of times per second that they rise and fall, different frequencies relating to different states of consciousness.

Alpha waves are the soft lighting of consciousness. In alpha we feel relaxed and available, not overly fixated on any specific thought or action, yet awake and alert. Mindfulness meditation has been shown to boost alpha levels in the brain, even outside of actual meditation. This could be part of why we sometimes feel calmer and more relaxed after a meditation session, and why long-term meditators report feeling more at ease overall.[11]

The other scientific finding I love is the link between increased gamma waves and loving-kindness or compassion meditation. Gamma waves are the fastest brain waves, oscillating at a frequency of 25-100 times per second. **A study of Tibetan Monks highly practiced in loving-kindness meditation found their gamma waves were off the charts, higher than any humans previously recorded**.[12] This led to one of the monks, a man named Matthieu Ricard, being dubbed "the happiest man in the world".

First-ever brain mitochondria map reveals energy secrets of the mind



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In new research published in *Nature*, scientists have produced the first comprehensive atlas of the tiny energy producers in the human brain. By slicing a donated brain into more than seven hundred small cubes and measuring both the number of mitochondria and their energy output in each piece, they discovered that mitochondria vary widely across brain regions. They found that the parts of the brain that evolved most recently in our lineage not only contain more mitochondria but also house mitochondria tuned to work more efficiently. This resource, called MitoBrainMap, lays the groundwork for linking energy use in the brain to mood, cognition, and the development of neurological and psychiatric disorders.

Mitochondria are microscopic structures inside nearly every cell that transform nutrients into the energy that powers all cellular activity. In neurons and support cells in the brain, this energy fuels memory formation, visual processing, and emotion regulation. Despite their importance, little was known about how many mitochondria the brain contains, whether they are spread evenly through its many regions, or how they differ in key ways. To begin answering these questions, the research team set out to chart the distribution, density, and functional diversity of brain mitochondria at a resolution comparable to that of a standard magnetic resonance scan.

"There's an emerging notion that energy is really important to health," explained Martin Picard, an associate professor of behavioral medicine and director of the Mitochondrial Psychobiology Group at Columbia University. "But we don't have a way to look at bioenergetics across the entire human brain."

Picard led the study along with Michel Thiebaut de Schotten, research director at the University of Bordeaux. "My interest in this research topic was sparked by a longstanding desire to bridge the gap between neuroimaging and histological biology," Thiebaut de Schotten told PsyPost. "Martin, who is a leading expert in mitochondrial research, has been a major source of inspiration. When we met, I was genuinely excited by the possibility of integrating our respective areas of expertise. Collaborating with him offered a unique opportunity to explore how mitochondrial biology could be linked with advanced MRI techniques."

To build the atlas, the team obtained a frozen coronal slice of the right hemisphere from a neurotypical fifty-four-year-old man with no history of neurological or psychiatric conditions. Working in a subzero environment, they used a computer-controlled milling device to engrave a three-millimeter grid into the tissue and then picked out each cube by hand. In total, 703 cubes were collected, each roughly the size of a large grain of sand.

In three-quarters of these cubes, they measured two markers of mitochondrial quantity—the activity of a key enzyme and the amount of mitochondrial DNA—and three markers of energy-transformation capacity by testing the activity of three enzymes in the respiratory chain. To ensure robust results, each measure was repeated in duplicate and corrected for any batch differences.

In parallel, the researchers performed single-nucleus gene sequencing on samples drawn from four distinct brain regions: the cortex, the hippocampus, the putamen (a movement-control region), and the corpus callosum (the brain's major communication pathway). This approach yielded data from more than

32,000 individual nuclei, allowing the team to relate mitochondrial measures to specific cell types.

Finally, they combined these laboratory data with MRI scans from nearly 2,000 healthy adults. Using statistical modeling, they linked common imaging signals to the mitochondrial features they had measured. By training the model on 80 percent of their tissue samples and testing it on the remaining 20 percent, they were able to predict mitochondrial density and energy output at the resolution of one cubic millimeter across the entire brain.

The results revealed striking regional and cellular patterns. Gray matter, which contains most of the brain's cell bodies and connections, showed both higher mitochondrial density and greater energy-production capacity than white matter, which is made up of long projections that carry signals. Within gray matter, evolutionarily newer regions—such as parts of the frontal and temporal lobes involved in complex thought and language—harbored more mitochondria that were tuned for efficient energy production. An exception was the putamen, a deeply buried structure involved in movement control, which displayed exceptionally high mitochondrial markers, perhaps reflecting its dense network of projections and synapses.

"One of the most surprising and exciting findings was the link between mitochondria and brain evolution," Thiebaut de Schotten explained. "We didn't expect to see such a clear relationship, and it opens up fascinating new questions about how mitochondrial function may have shaped the development of the human brain over time and how it will interact with future evolution."

Gene sequencing largely supported these biochemical findings. When the team examined expression levels of genes involved in mitochondrial energy production, they found higher expression in regions with greater enzyme activity. Although different cell types—neurons, support cells, blood-vessel cells, and others—showed subtle differences in mitochondrial gene activity, the strongest driver of variation was the brain region itself. In other words, a neuron in one part of the brain had a gene-activity profile more similar to its neighbors than to neurons in far-flung regions.

"One of the key takeaways from our study is that we now have a better understanding of how mitochondria—the energy processors of our cells—are distributed across the human brain on average," Thiebaut de Schotten said. "This is important because mitochondria play a vital role in brain function and health. Our next goal is to map these mitochondrial patterns in individual brains, which could eventually help us understand how they relate to brain health, aging, and neurological conditions."

To test how well their MRI-based model would generalize, the researchers applied it to a slice from the donor's occipital lobe, which had not been used in model training. The predicted patterns of mitochondrial density and energy capacity closely matched the laboratory measurements, giving confidence that routine brain scans can serve as a window into cellular energy factories. When the model was extended to every cubic millimeter of the standard brain reference, it produced three-dimensional maps that align with known imaging measures of brain evolution and variability.

"This work helps us understand the energetic basis of brain function and brain health," Picard told PsyPost. "Without energy, the brain is an inert fatty blob. But energized by mitochondria, the mind emerges and allows you to think, feel, and behave. We are, fundamentally, energetic processes. MitoBrainMap v1.0 helps us understand how energy flows to make this possible."

Despite its strengths, the study has clear limitations. Because the atlas is based on a single human brain, it remains to be seen how mitochondrial patterns vary among individuals of different ages, sexes, and health conditions. The tissue-preparation method for gene sequencing involved aggressive mechanical disruption, which may have biased which cell types survived the process. Future research will need to include samples from multiple donors and refine sequencing protocols to capture a broader array of cell types.

"A major limitation of our study is that our model and conclusions are based on data from a single brain," Thiebaut de Schotten noted. "While this provides valuable initial insights, studying more brains to understand how mitochondrial patterns vary across individuals is essential. Securing funding for this next phase, which is difficult in the current context, is a key priority, as it will allow us to explore individual differences and strengthen the broader applicability of our findings."

"The long-term goal is to noninvasively quantify mitochondrial biology using only MRI for both research and health monitoring," Picard said. "That would be amazing!"

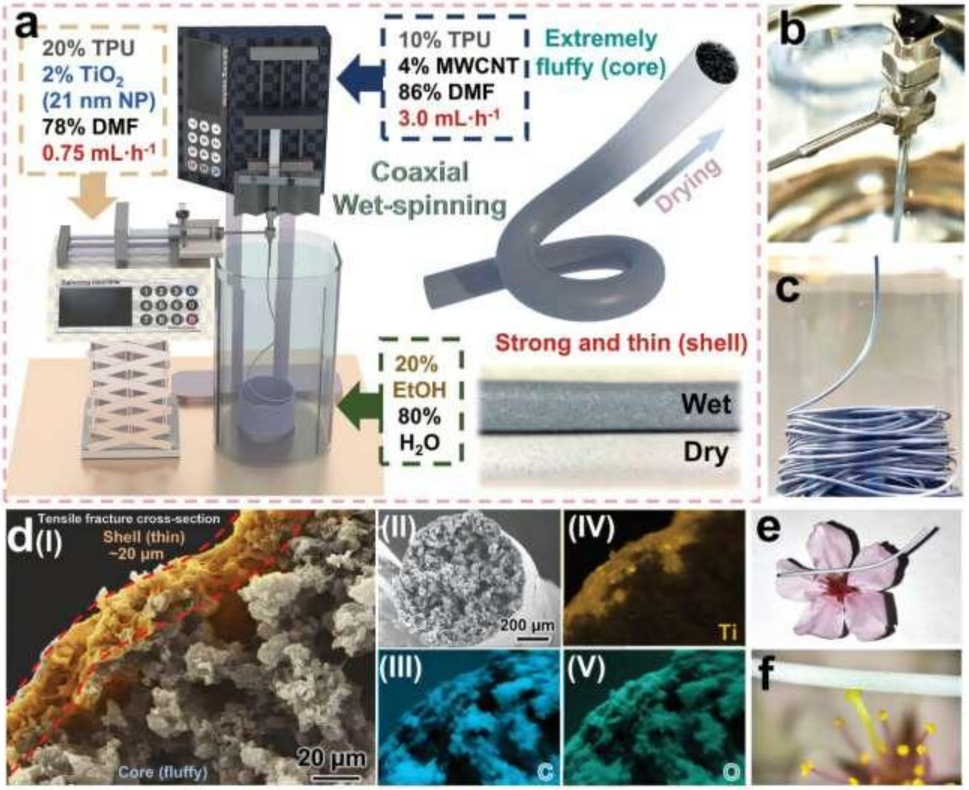
"Our work is showcased at http://www.humanmitobrainmap.bcblab.com," Thiebaut de Schotten added.

The study, "A human brain map of mitochondrial respiratory capacity and diversity," was authored by Eugene V. Mosharov, Ayelet M. Rosenberg, Anna S. Monzel, Corey A. Osto, Linsey Stiles, Gorazd B. Rosoklija, Andrew J. Dwork, Snehal Bindra, Alex Junker, Ya Zhang, Masashi Fujita, Madeline B. Mariani, Mihran Bakalian, David Sulzer, Philip L. De Jager, Vilas Menon, Orian S. Shirihai, J. John Mann, Mark D. Underwood, Maura Boldrini, Michel Thiebaut de Schotten, and Martin Picard.

APRIL 28, 2025

DNA-inspired flexible fiber design enhances sensors for wearables

by Shinshu University



Preparation of TT/MT fluffy core-shell fibers: a) Schematic diagram of wet-spinning and the proportion of slurry. b) Photo of the needle for wet-spinning. c) Photo of fibers during the wet-spinning process. d) Cross-sectional SEM image of TT/MT fluffy fibers and EDS map of the external structure of TT/MT fluffy fibers. e,f) Display of the lightweight TT/MT fibers. Credit: *Advanced Science* (2025). DOI: 10.1002/advs.202416564

A fiber sensor inspired by the shape of DNA, developed by researchers at Shinshu University, introduces a new design for more durable, flexible fiber sensors in wearables. Traditional fiber sensors have electrodes at both ends, which often fail under repeated movement when placed on body joints.

The proposed double-helical design, however, places both electrodes on one end, allowing the sensor to endure repeated stretching and movement, effectively addressing a key limitation of conventional wearable sensors.

Flexible fiber sensors are widely used in smart wearables, as their compact size and lightweight feel make them suitable for everyday use. However, current designs, commonly placed at joints, face limited application due to mechanical challenges. Traditional fiber sensors with electrodes at both ends are vulnerable when applied to joints like fingers or knees, where repeated movement pulls on connecting wires, causing them to break loose or produce measurement inaccuracies.

To solve this issue, a team of researchers from Shinshu University, Japan, has developed a new type of flexible sensor with a double-helical structure that mimics the shape of DNA. This new design places both electrodes on one end of the fiber, reducing strain during movement and significantly improving durability. Their findings were published online on February 4, 2025 in the journal *Advanced Science*.

"Effective electrode design is critical to the performance and lifespan of wearable sensors. But in one-dimensional fiber sensors, this has long been a challenge. Our design addresses this issue directly," says Associate Professor Chunhong Zhu, the lead author of the study from the Institute for Fiber Engineering and Science.

The researchers drew inspiration from the stability of DNA's double helix, which is maintained by hydrogen bonds between complementary base pairs. In a similar fashion, they twisted two specially designed coaxial fibers together to create a tightly bound, stable structure.

Each fiber is produced using a method called coaxial wet-spinning, with an insulating outer layer and a fluffy, conductive inner core. The core contains multi-walled carbon nanotubes (MWCNTs), while the outer layer includes thermoplastic polyurethane (TPU) and titanium dioxide (TiO_2) nanoparticles, which make the fibers fluffier and stronger.

After heat treatment, the two fibers naturally form a double helix with built-in positive and negative terminals on the same end, eliminating the need for complex wiring at both ends—a common problem in traditional designs. "The TT/MT dual-helical fiber has two electrodes at one end and a free end with no electrodes, greatly simplifying the wiring of flexible sensors," says Mr. Ziwei Chen, co-author of the study.

The resulting TT/MT dual-helical fiber sensor is remarkably slender, measuring less than 1 mm in diameter, making it easy to seamlessly integrate into wearable textiles. In addition, it proved to be highly durable, enduring repeated stretching and bending. In laboratory tests, it withstood over 1,000 stretching cycles and extended more than 300% beyond its original length without breaking.

With both electrodes located on the same side, the sensor can be used across joints with the side containing the electrodes attached to areas with limited movement, such as the back of the hand, cheeks, or knees, without risking wire damage. This opens up applications for tracking finger gestures, facial expressions, and gait movements, and even detecting breathing patterns during sleep.

Researchers have developed a flexible fiber sensor with a double-helical structure that places both electrodes on one end. This design improves durability, allowing the sensor to endure repeated stretching and bending, and makes it easier to integrate into wearable devices, especially for use on body joints. Credit: Associate Professor Chunhong Zhu from Shinshu University
In one test, the researchers placed the sensor inside a glove and used a machine-learning model to help it learn how to recognize finger movements. The glove was able to identify six common hand gestures with 98.8% accuracy. In another test, the sensor detected how long each finger pull lasted and used that to send Morse code wirelessly, showcasing its potential as a tool for assisting people with disabilities.

The design also shows promise for use in Bluetooth-connected wearables, enabling real-time remote monitoring for rehabilitation and sports training, according to the researchers. The team envisions these sensors being embedded in clothing for high-risk activities like mountaineering, where they could send emergency alerts in case of accidents, falls, or health issues such as hypoxia.

With this innovative design, the researchers hope to inspire the development of the next generation of intelligent fibers that are not only durable and sensitive but also easy to integrate into daily wear.

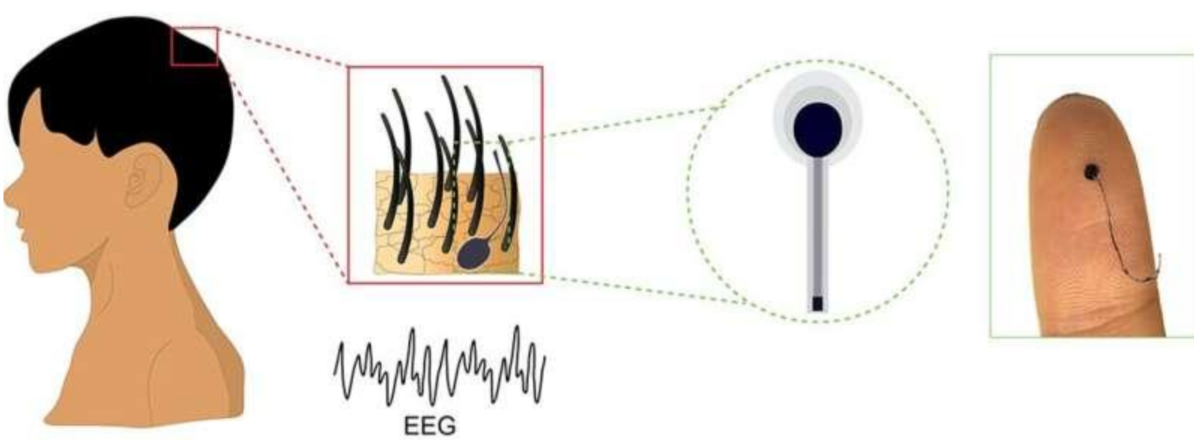
"Our design strategy, exemplified by the TT/MT dual-helical fiber highlighted in our study, also provides a versatile approach that can inspire the development of various intelligent fibers tailored for different applications," says Dr. Zhu.

More information: Ziwei Chen et al, Structure and Wiring Optimized TT/MT Double-Helical Fiber Sensors: Fabrication and Applications in Human Motion Monitoring and Gesture Recognition, *Advanced Science* (2025). DOI: 10.1002/advs.202416564
Journal information: Advanced Science

MAY 2, 2025

The future of brain activity monitoring may look like a strand of hair

by Christine Yu , Pennsylvania State University



The lightweight and flexible electrode, which looks like a strand of hair, attaches directly to the scalp and delivers stable, high-quality recordings of the brain's signals. Credit: Zhou Lab / Penn State. Creative Commons

The future of electroencephalography (EEG) monitoring may soon look like a strand of hair. In place of the traditional metal electrodes, a web of wires and sticky adhesives, a team of researchers from Penn State created a hairlike device for long-term, non-invasive monitoring of the brain's electrical activity. The lightweight and flexible electrode attaches directly to the scalp and delivers stable, high-quality recordings of the brain's signals.

EEG is critical for diagnosing and assessing neurological conditions like epilepsy and brain injuries. In some cases, clinicians need to monitor brain waves for longer periods of time, for example, to evaluate seizures, sleep disorders and conditions that affect the blood vessels and blood flow in the brain.

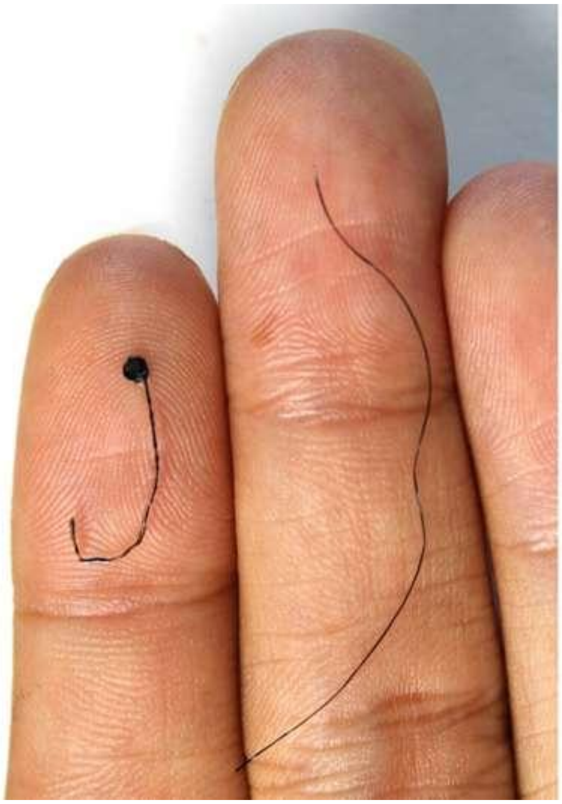
The researchers described the new electrodes, which were shown to maintain stable performance for over 24 hours of continuous wear, in a study published in the journal npj Biomedical Innovations. This technology holds promise for use in consumer health and wellness products, in addition to clinical health care applications, according to the researchers.

"This electrode allows for more consistent and reliable monitoring of EEG signals and can be worn without being noticeable, which enhances both functionality and patient comfort," said Tao Zhou, Wormley Family Early Career Professor of engineering science and mechanics and senior author on the paper.

EEG monitoring is a widely used method to measure the brain's electrical activity, Zhou explained. Small metal electrodes are placed on the scalp and pick up the faint electrical impulses generated by cells in the brain. The electrodes are attached to wires that are then connected to a machine that displays the brain's activity as patterns that look like waves.

The traditional EEG monitoring process, however, can be a cumbersome—and sometimes messy—affair. Its limitations make it difficult to use for continuous, long-term monitoring.

To get a good recording of the brain's activity, the electrodes need to conform to the scalp. Any gaps between the electrode and the skin or dense hair can diminish the quality of the recorded signal. Researchers and clinicians must apply gels to the scalp to maintain good surface-to-surface contact between the electrodes and skin and signal quality. For some people, though, the gels can cause skin irritation.



Comparison of the hairlike electrode, on left, and a human hair. Credit: Zhou Lab / Penn State. Creative Commons

It's a time-consuming process that must be repeated when the gels dry out, especially for someone needs to be monitored continuously or over the course of multiple sessions. The application and re-application process is imprecise, too, and can result in different amounts of gel used on the electrodes.

"This will change the impedance—or interface—between the electrodes and the scalp and it can affect the brain signal that's recorded," Zhou said. "We also don't always apply the electrodes in the exact same position either because we're human. But if you change the position, even a little bit, the brain signals you're monitoring can be different."

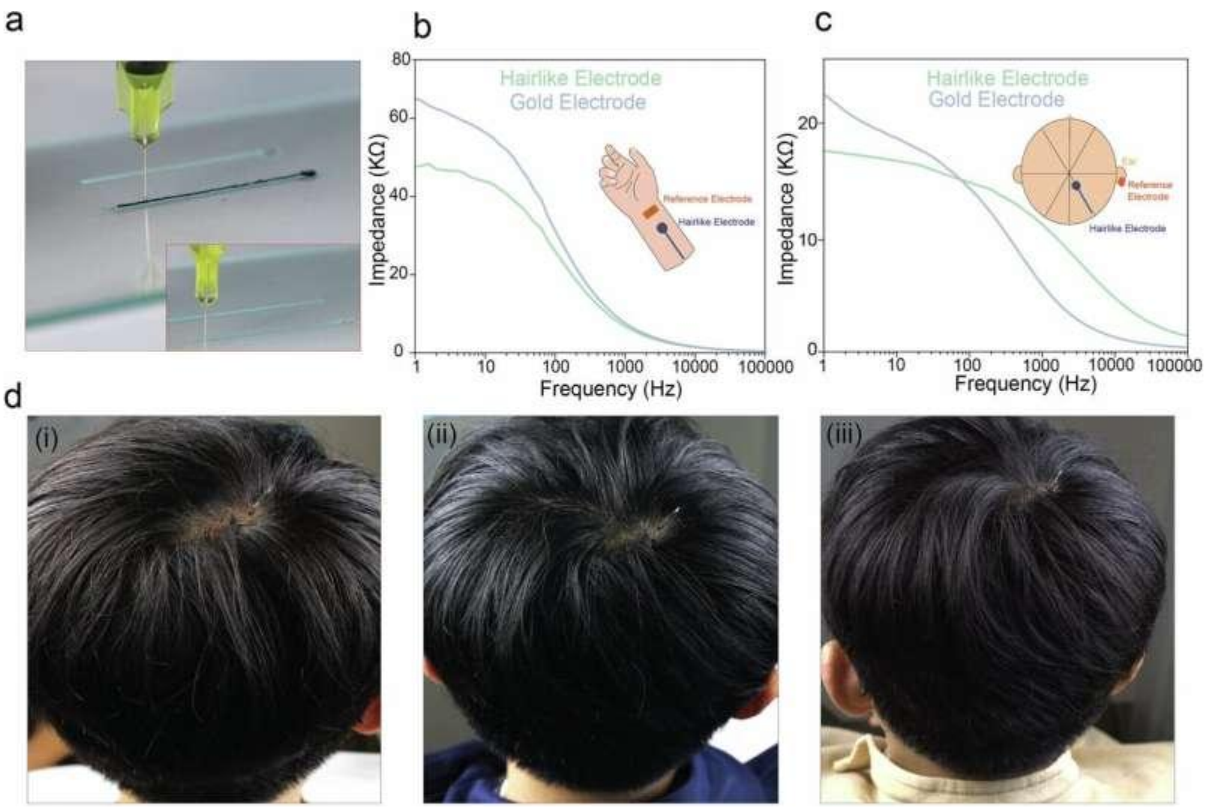
The conventional EEG electrodes are rigid, too, and can shift when someone moves their head, even slightly, which can compromise the data uniformity.

To address these limitations, the research team designed a small monitoring device that looks like a strand of hair and is made from 3D-printed hydrogel material. One end is the electrode. It looks like a small dot and captures the brain's electrical signals from the scalp. There's a long, thin wire-like component that extends from the electrode, which connects to the monitoring system.

The device also uses a 3D-printable bioadhesive ink that allows the electrode to stick directly onto the scalp without the need for any gloopy gels or other skin preparation. This minimizes the gap between the electrode and scalp, improving the signal quality. The lightweight, flexible and stretchable nature of the device also means that the device stays put—even when combing hair and donning and removing a baseball cap—and can be worn for longer periods of time, making it suitable for chronic monitoring.

The team found that the new device performed comparably to gold electrodes, the current standard electrodes used for EEG. However, the hairlike electrode maintained better contact between the electrode and skin and performed reliably for over 24 hours of continuous wear without any degradation in signal quality. Because the electrodes don't have to be removed and replaced like traditional EEG monitoring systems, they eliminate the risk of inconsistent data, even across different monitoring sessions.

"You don't have to worry if the position of the electrode has changed or if the impedance has changed because the electrodes haven't moved," Zhou said.



Printing of hairlike electrodes and characterization of their stability, electrical and mechanical properties. Credit: *npj Biomedical Innovations* (2025). DOI: 10.1038/s44385-025-00009-x

Unlike the traditional metal electrodes, the new electrodes mimic human hair and are inconspicuous on the head. Since the device is 3D-printed, Zhou explained that they can print the electrode in different colors to match a person's hair, too.

"This makes it discreet, and people may be more comfortable wearing this, especially if they require continuous EEG monitoring and need to wear the electrodes for an extended period of time," Zhou said.

Currently, the EEG is still wired; patients need to be connected to a machine while their brain activity is recorded. In the future, the researchers hope to make the system wireless so that people can move around more freely during recording sessions.

Other Penn State authors on the paper include lead authors Salahuddin Ahmed and Marzia Momin, both doctoral students in the Department of Engineering Science and Mechanics. Jiashu Ren, doctoral student in the Department of Engineering Science and Mechanics; Hyunjin Lee, doctoral student in the Department of Biomedical Engineering; Li-Pang Huang, research assistant; and Basma AlMahmood, undergraduate student in the Department of Physics also contributed to the paper.

Other authors include Chi-Ching Kuo, Archana Pandiyan and Loganathan Veeramuthu from the Department of Molecular Science and Engineering, National Taipei University of Technology.

More information: Salahuddin Ahmed et al, Stick-and-play bioadhesive hairlike electrodes for chronic EEG recording on human, *npj Biomedical Innovations* (2025). DOI: 10.1038/s44385-025-00009-x
Provided by Pennsylvania State University

MAY 14, 2025

Brain scans reveal what happens in the mind when insight strikes

by Robin Smith , Duke University

Examples of the hidden picture puzzles in the black/white images on the lower panel; corresponding real-world pictures on the upper panel. Credit: Maxi Becker et al

Have you ever been stuck on a problem, puzzling over something for what felt like ages without getting anywhere, but then suddenly the answer came to you like a bolt from the blue?

We've all experienced that "aha! moment," that sudden clarity or magical epiphany you feel when a new idea or perspective pops into your head as if out of nowhere.

Now, new evidence from brain imaging research shows that these flashes of insight aren't just satisfying—they actually reshape how your brain represents information, and help sear it into memory.

Led by researchers at Duke University and Humboldt and Hamburg Universities in Germany, the work has implications for education, suggesting that fostering "eureka moments" could help make learning last beyond the classroom.

If you have an aha experience when solving something, "you're actually more likely to remember the solution," said first author Maxi Becker, a postdoctoral fellow at Humboldt University in Berlin.

The findings were published May 9 in the journal *Nature Communications*.

How the study worked

In the study, the researchers used a technique called functional magnetic resonance imaging (fMRI) to record people's brain activity while they tried to solve visual brain teasers. The puzzles required them to "fill in the blanks" of a series of two-tone images with minimal detail, using their perception to complete the picture and identify a real-world object.

Such hidden picture puzzles serve as small-scale proxies for bigger eureka moments. "It's just a little discovery that you are making, but it produces the same type of characteristics that exist in more important insight events," said senior author Roberto Cabeza, a professor of psychology and neuroscience at Duke.

For each puzzle the participants thought they solved, the researchers asked whether the solution just popped into their awareness in a flash of sudden insight, or whether they worked it out in a more deliberate and methodical way, and how certain they were of their answer.

The results were striking.

Participants tended to recall solutions that came to them in a flash of insight far better than ones they arrived at without this sense of epiphany. Furthermore, the more conviction a person felt about their insight at the time, the more likely they were to remember it five days later when the researchers asked them again.

"If you have an 'aha! moment' while learning something, it almost doubles your memory," said Cabeza, who has been studying memory for 30 years. "There are few memory effects that are as powerful as this."

A number of changes in the brain may cause people to have better memory for "aha! moments," the researchers found.

A boost for memory

They discovered that flashes of insight trigger a burst of activity in the brain's hippocampus, a cashew-shaped structure buried deep in the temporal lobe that plays a major role in learning and memory. The more powerful the insight, the greater the boost.

They also found that the activation patterns across the participants' neurons changed once they spotted the hidden object and saw the image in a new light—particularly in certain parts of the brain's ventral occipito-temporal cortex, the region responsible for recognizing visual patterns. The stronger the epiphany, the greater the change in those areas.

"During these moments of insight, the brain reorganizes how it sees the image," said Becker, who did the work in the Cabeza lab.

Lastly, stronger "aha!" experiences were associated with greater connectivity between these different brain regions. "The different regions communicate with each other more efficiently," Cabeza said.

The current study looked at brain activity at two specific moments in time, before and after the eureka moment when the lightbulb appeared. As a next step, the researchers plan to look more closely at what happens during the few seconds in between that allows people to finally see the answer.

"Insight is key for creativity," Cabeza said. In addition to shedding light on how the brain comes up with creative solutions, the findings also lend support for inquiry-based learning in the classroom.

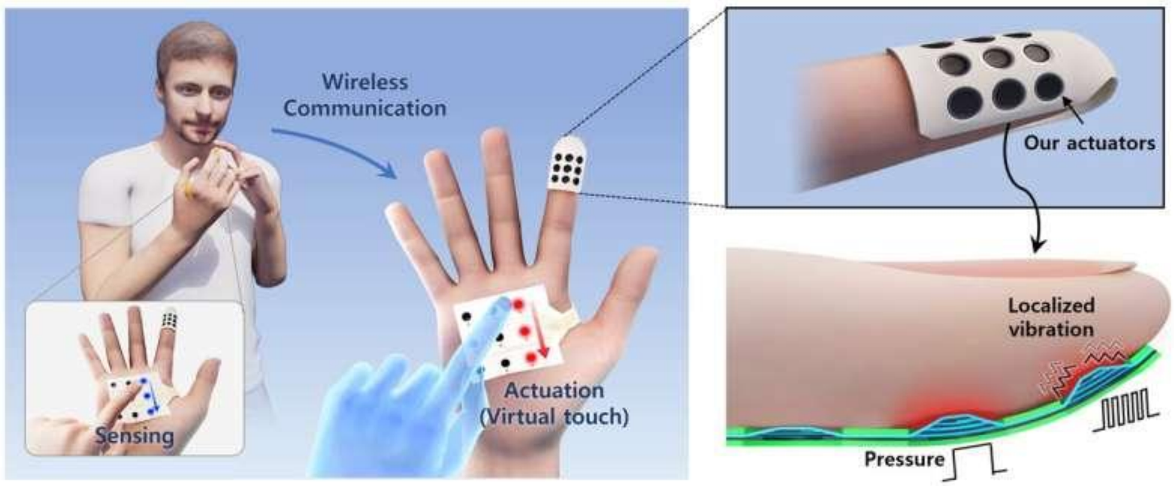
"Learning environments that encourage insight could boost long-term memory and understanding," the researchers wrote.

More information: Maxi Becker et al, Insight predicts subsequent memory via cortical representational change and hippocampal activity, *Nature Communications* (2025). DOI: 10.1038/s41467-025-59355-4
Journal information: Nature Communications
Provided by Duke University

MAY 8, 2025

Wearable haptics get thinner: A flexible haptic patch lets you feel the virtual world

by Jung-Hwan Youn



Scenario of bidirectional tactile communication using haptic patch. Credit: Hee-kyung Kwon

As virtual reality (VR) and augmented reality (AR) technologies rapidly evolve, the demand for more immersive, multisensory experiences grows alongside them. Among the key frontiers is tactile feedback—the ability to physically feel the virtual world.

While wearable haptic suits equipped with vibrational motors or fluidic actuators have made strides in enhancing realism, delivering precise, diverse, and natural tactile sensations to the skin remains a major challenge. The limitation has largely stemmed from a lack of compact, lightweight, high-performance tactile actuators.

That's where our research takes a bold step forward. My colleagues and I have developed a new class of thin, flexible tactile actuators designed to deliver rich, nuanced haptic feedback directly to the skin.

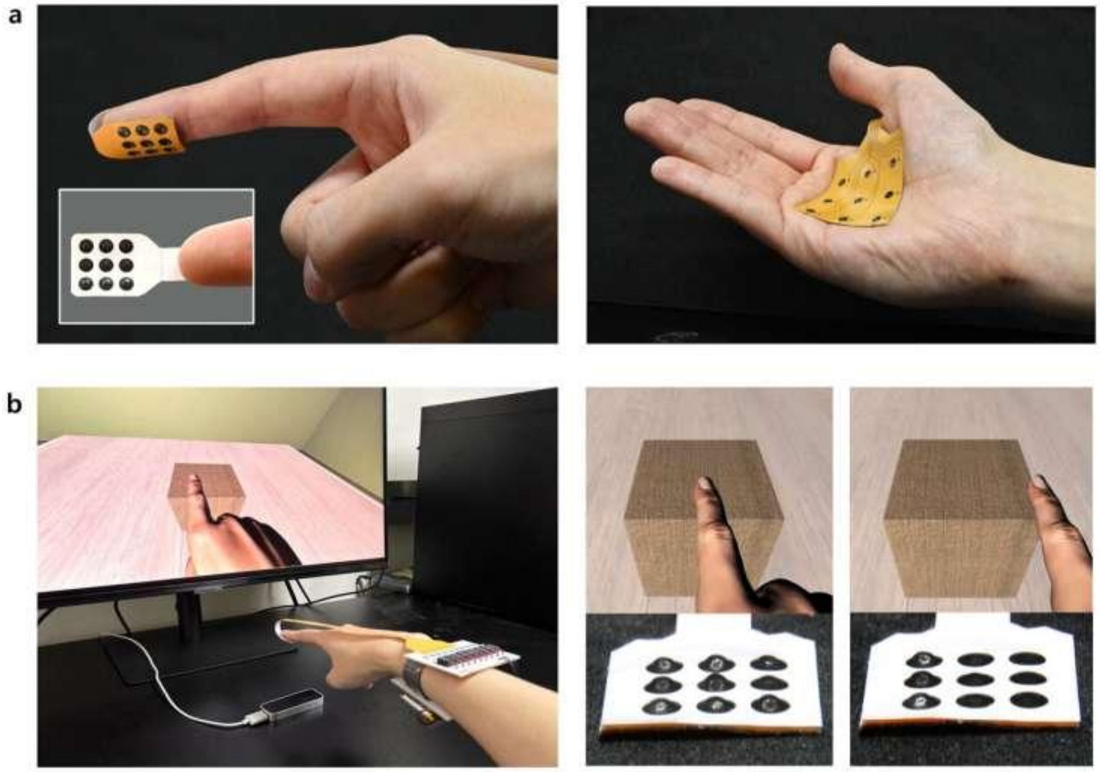
Our work is published in the journal *Science Advances*.

Actuation of our tiny tactile actuators. Credit: Hee-kyung Kwon

Tiny, powerful tactile actuators

To provide dense and varied tactile sensations, actuators must be both compact and capable of generating a wide range of feedback. Addressing this, we created a novel tactile actuator based on a dielectric elastomer actuator (DEA). DEAs produce significant area expansion when voltage is applied, thanks to the phenomenon known as Maxwell stress. By combining a DEA with a small compressive spring, we successfully converted this area expansion into a linear displacement.

The result is a remarkably small actuator measuring just 6 mm in diameter and 1.1 mm in thickness. Despite its thin, compact design, the actuator can produce tactile sensations ranging from pressure to high-frequency vibrations, all while consuming less than 60 mW of power. Impressively, the actuator is powerful enough to lift a 25 g weight, despite its very light weight of 32 mg.



(a) Thin flexible haptic patch for fingertip and palm of the hand. (b) VR scenario with synchronized contact geometry of virtual box. Credit: Hee-kyung Kwon

A flexible, skin-conformal haptic patch

Building upon this actuator, we developed a flexible haptic patch incorporating a dense array of nine actuators within a small fingerpad-sized area. Fabricated on a thin, flexible printed circuit board (PCB), the entire patch weighs only 0.3 g and can comfortably conform to the contours of the skin without hindering natural hand movements. Each actuator is individually controlled, enabling the patch to dynamically render textures, simulate the 3D surfaces of virtual objects, and deliver intricate patterns of tactile feedback.

To complete the system, we integrated a reflective photomicrosensor array, allowing the patch not only to deliver haptic feedback but also to sense touch. This bidirectional capability opens the door for wireless tactile communication in VR environments or between users, where touch sensations can be encoded, transmitted, and recreated in real time.

Looking ahead

Our work introduces a thin, flexible, and lightweight wearable haptic patch, made possible by this next-generation tactile actuator technology. Beyond VR and AR applications, we believe these actuators hold potential for broader use, including in miniaturized robotics, advanced prosthetics, and medical devices.

By bridging the gap between the digital and physical worlds, this technology marks an exciting step toward making touch a natural part of our digital experiences.

This story is part of Science X Dialog, where researchers can report findings from their published research articles. Visit this page for information about Science X Dialog and how to participate.

More information: Jung-Hwan Youn et al, Skin-attached haptic patch for versatile and augmented tactile interaction, *Science Advances* (2025). DOI: 10.1126/sciadv.adt4839
Journal information: Science Advances

Jung-Hwan is an postdoctroral researcher at the University of Illinois Urbana-Champaign. Before joining, he worked as a post-doc at the Electronics Telecommunication Research Institute (ETRI). He finished his Ph.D. in Korea Advanced Institute of Science and Techonology (KAIST). His research interests include haptics, soft robotics and human-robot interaction.

MAY 12, 2025

The how and why of the brain's division across hemispheres

by Massachusetts Institute of Technology

Credit: Pixabay/CC0 Public Domain

People have a lot of misconceptions about what the brain's left and right hemispheres do, but one well-known aspect of this division may be even more true than people realize: The brain not only splits up visual spatial perception—processing what's on our left in the right hemisphere and what's on our right in the left hemisphere—it takes cognitive advantage of that.

A new review by MIT neuroscientists explains what the field has learned about this division of labor, the trade-off it involves and how the brain ultimately bridges the divide.

"People hear all these myths about the left brain being more analytical and the right brain being more artistic, or people being right-brained vs. left-brained; 99% of that is nonsense," said paper co-author Earl K. Miller, Picower Professor in The Picower Institute for Learning and Memory and the Department of Brain and Cognitive Sciences at MIT. "You think with your whole brain."

But when it comes to visual spatial perception, the brain has evolved separate neural resources for the right vs. left sides of gaze even in later stages of cognitive processing, Miller said. Why? To optimize its capacity.

"It's for good reason," said Miller, who co-authored the review in the journal *Neuropsychologia* with Picower Institute research scientist Scott Brincat.

"Perceptual capacity is limited—you can only take in so much at once. If your capacity is fully tied up on the right side of your gaze, you might miss a threat approaching on the left. Splitting resources between both sides helps avoid dangerous perceptual blind spots."

Separated sight

When Miller was in graduate school, he said, he was taught that the brain neatly divided its visual perception of space between hemispheres until the information reached the prefrontal cortex where it became seamlessly blended. But experiments by Miller and Brincat, as well as many other researchers, have been accumulating evidence to refine that view over the last 20 years.

These studies have shown that even in the prefrontal cortex, neural encoding of information about where an object is, is still biased toward the "contralateral" hemisphere, or the hemisphere opposite of where the object appears in the field of view.

"As a result, the two hemispheres appear to function surprisingly independently, even for high-level cognitive functions like attention and working memory," the authors wrote.

The evidence is apparent in measurements of the brain waves produced by coordinated networks of neurons in each hemisphere. Gamma frequency wave power increases in frontal brain hemispheres when they consider the visual stimuli that appear on the contralateral side.

Meanwhile, studies for decades (including one in 1971) have shown that people and animals can remember more things if their presentation is split between hemispheres rather than presented all on one side. Neuroscientists call this the "bilateral advantage," though it is not perfect. People don't track multiple things, even if split across both sides, as well as they track just one thing on either side.

People also exhibit individualized differences in perceptual capacity across the visual field. Miller has founded the startup company SplitSage to measure these differences with the goal of helping people with visually oriented complex tasks to improve their performance.

Notably, the studies that Brincat and Miller review in the new paper show that the split bias between hemispheres applies only to spatial information—the where something is. Other features like color or shape are processed by both hemispheres.

Seamless sight

If the brain maintains a separation in its processing of spatial visual perception, even at the stage of allocating attention and juggling objects in working memory, why aren't we confused or surprised when a bird flying from our left passes into the right side of our field of view? We also easily handle cases where our shifting gaze moves an object from one eye's field of view to the other's.

"We experience a seamless world," Miller said.

It turns out that the brain accomplishes the "handoff" from one hemisphere to the other much like two cellular towers do for your phone as you drive around, according to neural activity measurements in studies such as one in 2014 and one that Brincat and Miller led in 2021.

"As a tracked target approaches the visual midline, the hemisphere about to receive the target shows a ramp-up of activity well before the crossing time, as if it is anticipating the target," the authors wrote.

"Further, activity in the sending hemisphere remains high well after the crossing. Thus, for up to a second or more, neural signals reflecting the target are shared across both hemispheres. It is as if both hemispheres are holding the baton."

As with the "bilateral advantage," there is a small performance cost when this transfer happens, studies show.

Deficits in interhemispheric connectivity or synchrony are apparent in neurological and psychiatric diseases including Alzheimer's, anxiety, depression, schizophrenia, obsessive-compulsive disorder and autism spectrum disorders, the authors note. Brincat and Miller's review emphasizes that such disruptions could affect cognition.

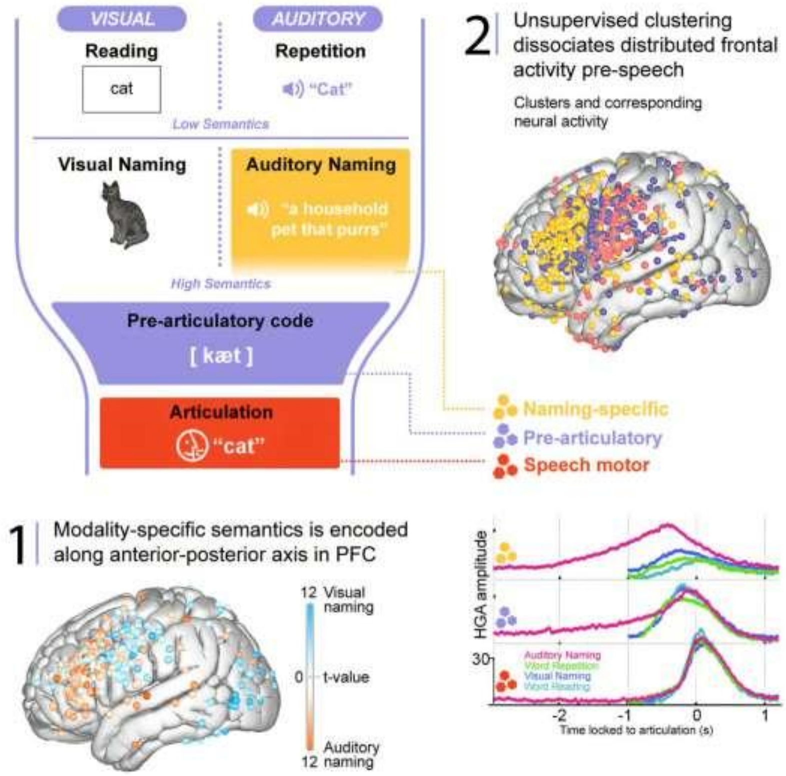
"A foundational understanding of interhemispheric processing, combined with interventions translatable to human patients, offers hope for developing novel network-level treatments," they wrote.

More information: Scott L. Brincat et al, Cognitive independence and interactions between cerebral hemispheres, *Neuropsychologia* (2025). DOI: 10.1016/j.neuropsychologia.2025.109153
Journal information: Neuropsychologia
Provided by Massachusetts Institute of Technology

MAY 13, 2025

Mapping the brain's naming network: New insights into how people retrieve words during speech

by NYU Tandon School of Engineering



Credit: *Cell Reports* (2025). DOI: 10.1016/j.celrep.2025.115677

How are we able to recall a word we want to say? This basic ability, called word retrieval, is often compromised in patients with brain damage. Interestingly, many patients who can name words they see, like identifying a pet in the room as a "cat," struggle with retrieving words in everyday discourse.

Scientists have long sought to understand how the brain retrieves words during speech. A new study by researchers at New York University sheds light on this mystery, revealing a left-lateralized network in the dorsolateral prefrontal cortex that plays a crucial role in naming.

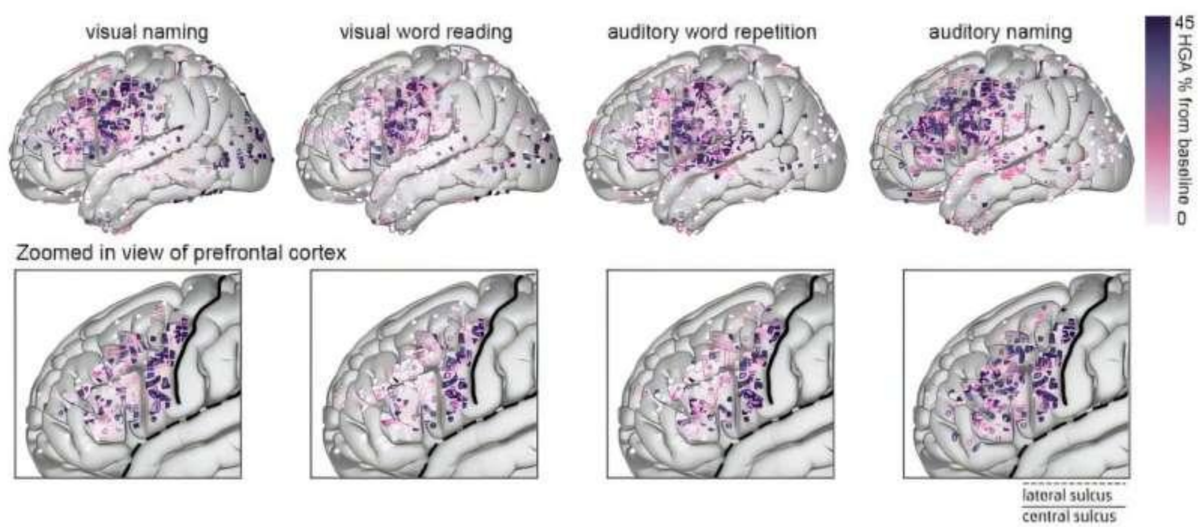
The findings, published in *Cell Reports*, provide new insights into the neural architecture of language, offering potential applications for both neuroscience and clinical interventions.

Word retrieval is a fundamental aspect of human communication, allowing us to link concepts to language. Despite decades of research, the exact neural dynamics underlying this process—particularly in natural auditory contexts—remain poorly understood.

NYU researchers—led by Biomedical Engineering Graduate Student Leyao Yu and Associate Professor of Biomedical Engineering at NYU Tandon and Neurology at NYU Grossman School of Medicine Adeen Flinker—recorded electrocorticographic (ECoG) data from 48 neurosurgical patients to examine the spatial and temporal organization of language processing in the brain.

By using unsupervised clustering techniques, the researchers identified two distinct but overlapping networks responsible for word retrieval. The first, a semantic processing network, was located in the middle and inferior frontal gyri. This network was engaged in integrating meaning and was sensitive to how surprising a word was within a given sentence.

The second, an articulatory planning network, was situated in the inferior frontal and precentral gyri, which played a crucial role in speech production, regardless of whether words were presented visually or auditorily.



Neural dynamics of prefrontal cortex, showing peak activity in the inferior frontal gyrus and middle frontal gyrus prior to speaking, including the strongest activation during auditory naming tasks. Credit: NYU Tandon School of Engineering

Auditory naming and the prefrontal cortex

The study builds upon decades of work in language neuroscience. Previous research suggested that different regions of the brain were responsible for retrieving words depending on whether they were seen or heard. However, earlier studies relied on methods with limited temporal resolution, leaving many unanswered questions about how these networks interact in real time.

By leveraging the high spatial and temporal resolution of ECoG, the researchers uncovered a striking ventral-dorsal gradient in the prefrontal cortex. They found that while articulatory planning was localized ventrally, semantic processing was uniquely represented in a dorsal region of the inferior frontal gyrus and middle frontal gyrus—a previously underappreciated hub for language processing.

"These findings suggest that a missing piece in our understanding of language processing lies in this dorsal prefrontal region," explains lead author Leyao Yu. "Our study provides the first direct evidence that this area is involved in mapping sounds to meaning in an auditory context."

Implications for neuroscience and medicine

The study has far-reaching implications, not only for theoretical neuroscience but also for clinical applications. Language deficits, such as anomia—the inability to retrieve words—are common in stroke, brain injury, and neurodegenerative disorders. Understanding the precise neural networks involved in word retrieval could lead to better diagnostics and targeted rehabilitation therapies for patients suffering from these conditions.

Additionally, the study provides a roadmap for future research in brain-computer interfaces (BCIs) and neuroprosthetics. By decoding the neural signals associated with naming, scientists could potentially develop assistive devices for individuals with speech impairments, allowing them to communicate more effectively through direct brain-computer communication.

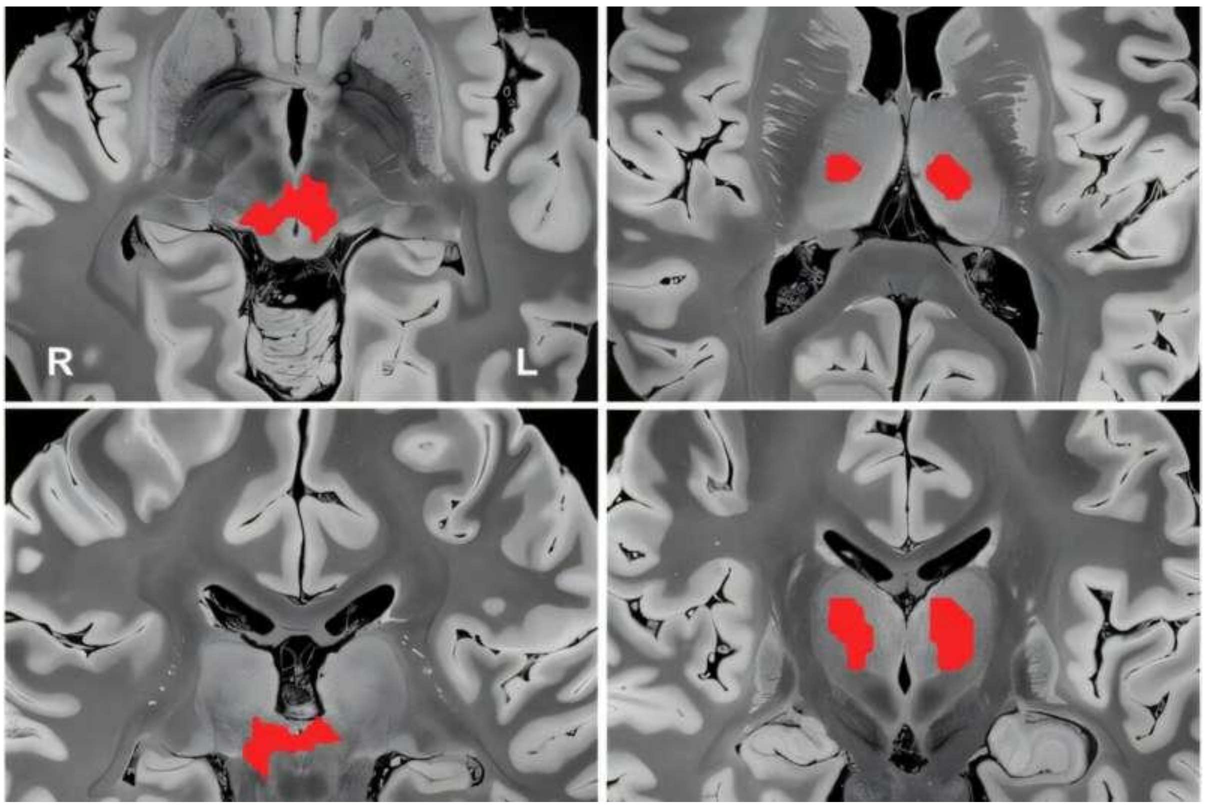
For now, one thing is clear: our ability to name the world around us is not just a simple act of recall, but the result of a sophisticated and finely tuned neural system—one that is now being revealed in greater detail than ever before.

More information: Leyao Yu et al, A left-lateralized dorsolateral prefrontal network for naming, *Cell Reports* (2025). DOI: 10.1016/j.celrep.2025.115677
Journal information: Cell Reports
Provided by NYU Tandon School of Engineering

MAY 15, 2025

Deep brain regions link all senses to consciousness, study finds

by Karen Guzman, Yale University



Midbrain and central thalamus show shared subcortical early activations (increases), observed in 11 tasks across four sensory modalities, including, vision, audition, taste, and touch. Credit: *NeuroImage* (2025). DOI: 10.1016/j.neuroimage.2025.121224

A Yale-led study shows that the senses stimulate a region of the brain that controls consciousness—a finding that might inform treatment for disorders related to attention, arousal, and more.

Humans perceive and navigate the world around us with the help of our five senses: sight, hearing, touch, taste and smell. And while scientists have long known that these different senses activate different parts of the brain, a new Yale-led study indicates that multiple senses all stimulate a critical region deep in the brain that controls consciousness.

The study, published in the journal *NeuroImage*, sheds new light on how sensory perception works in the brain and may fuel the development of therapies to treat disorders involving attention, arousal, and consciousness.

In the study, a research team led by Yale's Aya Khalaf focused on the workings of subcortical arousal systems, brain structure networks that play a crucial role in regulating sleep-wake states. Previous studies on patients with disorders of consciousness—such as coma or epilepsy—have confirmed the influence of these systems on states of consciousness.

But prior research has been largely limited to tracking individual senses. For the new study, researchers asked if stimuli from multiple senses share the same subcortical arousal networks. They also looked at how shifts in a subject's attention might affect these networks.

For the study, researchers analyzed fMRI (functional magnetic resonance imaging) datasets collected from 1,561 healthy adult participants as they performed 11 different tasks using four senses: vision, audition, taste, and touch.

They made two important discoveries: that sensory input does make use of shared subcortical systems and, more surprisingly, that all input—regardless of which sense delivered the signal—stimulates activity in two deep brain regions, the midbrain reticular formation and the central thalamus, when a subject is sharply focused on the senses.

The key to stimulating the critical central brain regions, they found, were the sudden shifts in attention demanded by the tasks.

"We were expecting to find activity on shared networks, but when we saw all the senses light up the same central brain regions while a test subject was focusing, it was really astonishing," said Khalaf, a postdoctoral associate in neurology at Yale School of Medicine and lead author of the study.

The discovery highlighted how key these central brain regions are in regulating not only disorders of consciousness, but also conditions that impact attention and focus, such as attention deficit hyperactivity disorder. This finding could lead to better targeted medications and brain stimulation techniques for patients.

"This has also given us insights into how things work normally in the brain," said senior author Hal Blumenfeld, the Mark Loughridge and Michele Williams Professor of Neurology who is also a professor in neuroscience and neurosurgery and director of the Yale Clinical Neuroscience Imaging Center. "It's really a step forward in our understanding of awareness and consciousness."

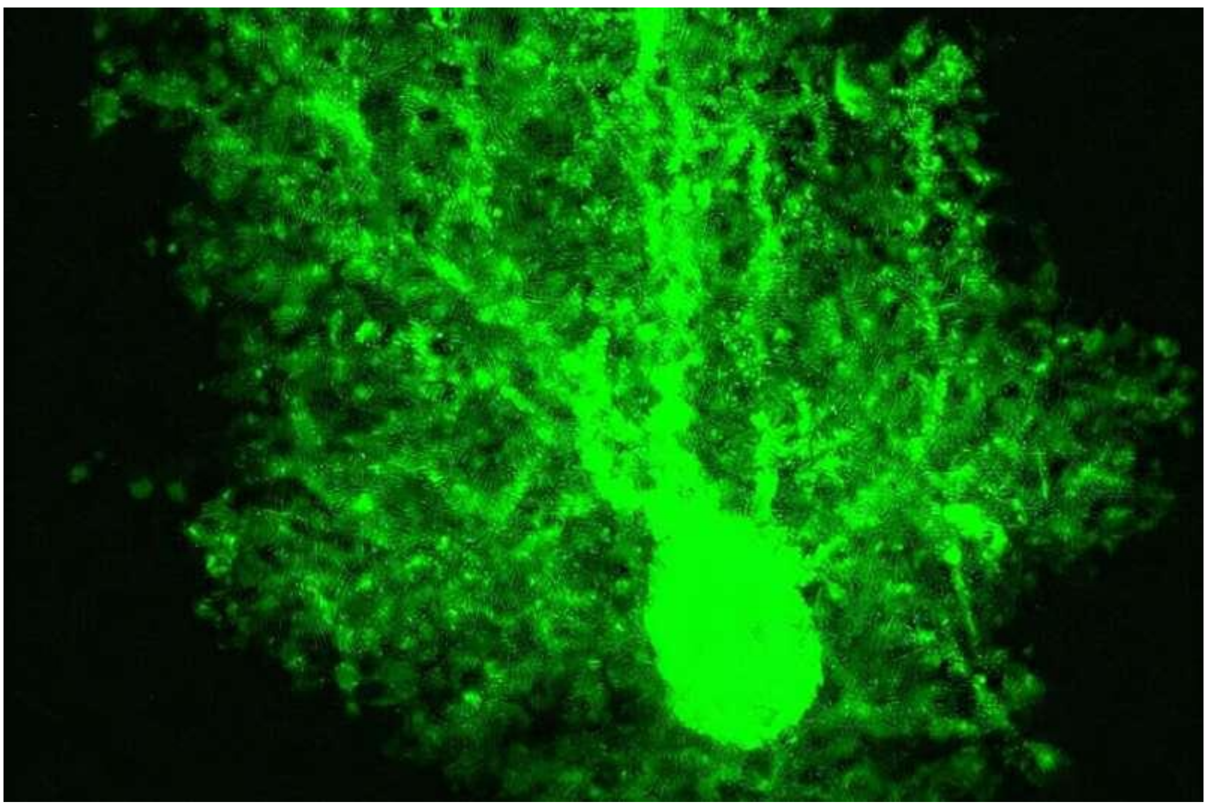
Looking across senses, this is the first time researchers have seen a result like this, said Khalaf, who is also part of Blumenfeld's lab.

"It tells us how important this brain region is and what it could mean in efforts to restore consciousness," she said.

More information: Aya Khalaf et al, Shared subcortical arousal systems across sensory modalities during transient modulation of attention, *NeuroImage* (2025). DOI: 10.1016/j.neuroimage.2025.121224
Journal information: NeuroImage
Provided by Yale University

MAY 15, 2025

An overlooked cell type orchestrates brain rewiring during states of heightened attention by Washington University in St. Louis



Researchers at WashU Medicine have shown in mice that brain cells known as astrocytes are required for a signaling chemical called norepinephrine to modify brain activity, changing the textbook understanding that norepinephrine acts directly on neurons. Above, a mouse astrocyte labeled with a fluorescent green marker. Credit: Yifan Wu

Researchers at Washington University School of Medicine in St. Louis have upended the decades-old dogma of how connections between brain cells are rearranged during states of heightened vigilance or attention. The team found that a brain chemical associated with alertness, attention and learning alters brain connectivity and function not by acting directly on neurons, the cells known for their quick transmission of information, but through the work of astrocytes, another, slower-acting type of brain cell that is often overlooked in the field of neuroscience.

The discovery, published in *Science*, fundamentally changes current understanding about the determinants of brain network communication and activity. It also calls for greater focus on astrocytes as therapeutic targets in the treatment of attention, memory and emotional disorders.

"Textbooks tell us that neuromodulators like norepinephrine fine-tune neurons directly—in fact, textbooks tell us that everything in the brain is about neurons," said Thomas Papouin, Ph.D., assistant professor of neuroscience at WashU Medicine and the senior author of the study. "It seems that a lot of brain wiring and activity is probably orchestrated by astrocytes, on slower timescales. This is the type of discovery that profoundly reshapes our understanding of how the brain works."

From the brain's wallflower to center stage

For the brain to dedicate itself to tasks that need attention, or to respond to unexpected stimuli like a fire alarm, it needs to be able to rewire itself by changing how brain cells communicate. This process is driven by the release of chemicals known as neuromodulators, including norepinephrine, in the brain. How these neuromodulators reorganize communication in the brain is poorly understood. The assumption for the past 80 years has been that neuromodulator chemicals act on neurons.

Meanwhile, for at least 30 years, astrocytes have been shown to contact and interact with synapses, which are the specialized structures where neurons communicate with one another. Researchers have long suspected that astrocytes have the potential to rearrange communication between neurons, and therefore, the flow of information in the brain.

Because of their very fine and sprawling shape, these cells are ideally positioned to monitor and detect neuromodulators like norepinephrine. "We wanted to test the idea that perhaps neuromodulation of synapses by norepinephrine is an astrocyte business," Papouin said.

To do so, Papouin and his team stimulated norepinephrine secretion from mouse brain cells or exposed mouse brain slices to norepinephrine and found that norepinephrine weakened connections between neurons, as has been known for decades. However, researchers found that norepinephrine also triggered activity among surrounding astrocytes. Once triggered by norepinephrine, astrocytes produced a second chemical that they released onto synapses, which caused the dampening of synapse activity.

Even when neurons' ability to directly sense norepinephrine was removed, norepinephrine was still able to rearrange neuronal connections. When astrocytes' ability to sense or respond to norepinephrine was taken offline, on the other hand, norepinephrine was unable to reorganize neuronal connectivity.

Their findings indicate that neuromodulators such as norepinephrine rearrange neuronal connections in the brain by signaling through astrocytes rather than directly onto neurons.

The results also suggest that targeting astrocytes could be an effective way to reshape brain activity to potentially treat brain disorders. Papouin's team has started looking at existing drugs that are believed to act on neurons, to see if they require astrocytes to be effective. If so, perhaps astrocytes could be targeted directly for therapeutic purposes.

"There are so many drugs out there that interfere with norepinephrine signaling in the brain, in particular in the treatment of ADHD or depression. I wonder how many of them require astrocytes to modify brain activity," said Papouin.

More information: Katheryn B. Lefton et al, Norepinephrine signals through astrocytes to modulate synapses, *Science* (2025). DOI: 10.1126/science.adq5480. www.science.org/doi/10.1126/science.adq5480
Journal information: Science
Provided by Washington University in St. Louis

MAY 13, 2025

Long working hours may alter brain structure, preliminary findings suggest

by British Medical Journal

Long working hours may alter the structure of the brain, particularly the areas associated with emotional regulation and executive function, such as working memory and problem solving, suggest the findings of preliminary research, published online in *Occupational & Environmental Medicine*.

Ultimately, overwork may induce neuroadaptive changes that might affect cognitive and emotional health, say the researchers.

Long working hours have been linked to heightened risks of cardiovascular disease, metabolic disorders, and mental health issues. And the International Labor Organization (ILO) estimates that overwork kills more than 800,000 people every year, note the researchers.

While the behavioral and psychological consequences of overwork are reasonably well understood, the underlying neurological mechanisms and anatomical changes aren't, they add.

To explore this further, the researchers deployed structural brain volume analysis to compare the impact of overwork on specific brain regions in health care workers routinely clocking up long working hours, defined as 52 or more a week.

They drew on data from the Gachon Regional Occupational Cohort Study (GROCS) and from MRI scans carried out for a research project on the effects of working conditions on brain structure.

Participants in GROCS were asked to have an additional MRI scan, and the final analysis included 110 people after excluding those with missing data or poor MRI image quality. Most were clinicians: 32 worked excessive weekly hours (28%); 78 worked standard hours.

Those putting in long working hours every week were significantly younger, had spent less time in work and were more highly educated than those clocking up standard hours.

Differences in brain volume were assessed using voxel-based morphometry (VBM)—a neuroimaging technique that identifies and compares regional differences in levels of gray matter—and atlas-based analysis, which uses pre-defined references to identify and label structures in images like brain scans.

Comparative analysis of the findings showed that people who worked 52 or more hours a week displayed significant changes in brain regions associated with executive function and emotional regulation, unlike participants who worked standard hours every week.

For example, atlas-based analysis revealed a 19% increase in the volume of the middle frontal gyrus among those clocking up long working hours compared with those working standard hours.

This part of the brain has a major role in various cognitive functions, particularly in the frontal lobe. It's involved in attention, working memory, and language-related processing.

VBM showed peak increases in 17 regions, including the middle frontal gyrus, the superior frontal gyrus, which is involved in attention, planning, and decision-making, and the insula.

The insula has a key role in integrating sensory, motor, and autonomic feedback from the body. It's involved in emotional processing, self-awareness, and understanding social context.

This is a small observational snapshot study, and as such, no firm conclusions can be drawn about cause and effect. And the researchers acknowledge that in the absence of long-term data, it's unclear whether these structural changes are a consequence of overwork or a predisposing factor.

But they nevertheless point out, "While the results should be interpreted cautiously due to the exploratory nature of this pilot study, they represent a meaningful first step in understanding the relationship between overwork and brain health."

They add, "Notably, the increased brain volumes observed in overworked individuals may reflect neuroadaptive responses to chronic occupational stress, although the exact mechanisms remain speculative."

They continue, "The observed changes in brain volume may provide a biological basis for the cognitive and emotional challenges often reported in overworked individuals. Future longitudinal and multi-modal neuroimaging studies are warranted to confirm these findings and elucidate the underlying mechanisms."

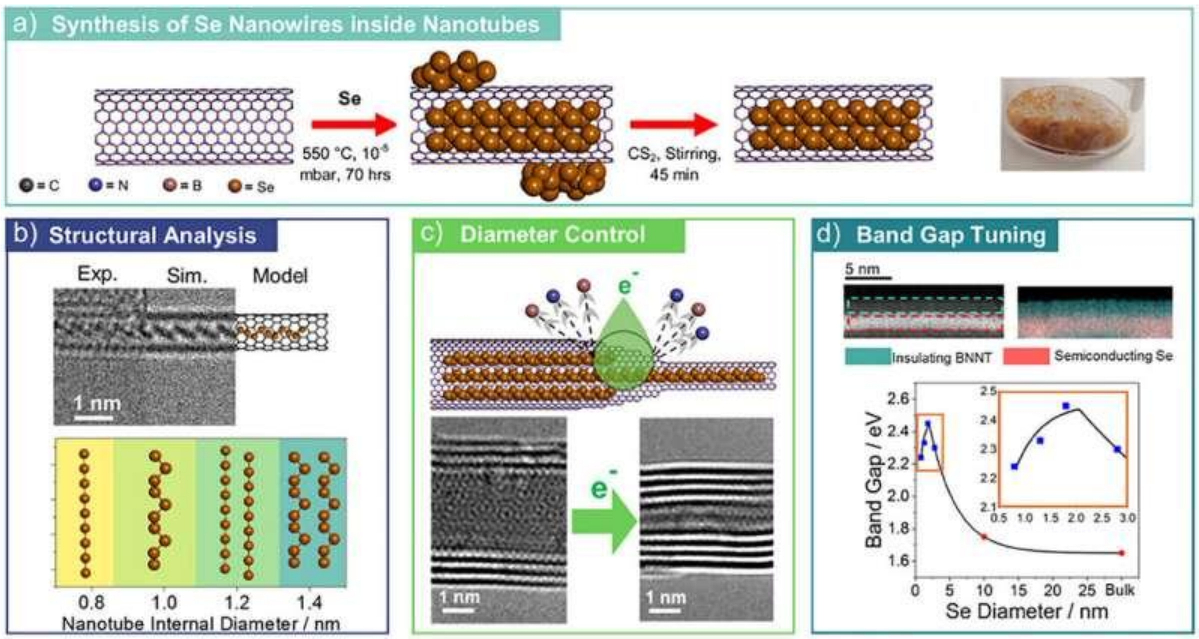
And they conclude, "The results underscore the importance of addressing overwork as an occupational health concern and highlight the need for workplace policies that mitigate excessive working hours."

More information: Overwork and changes in brain structure: a pilot study, *Occupational and Environmental Medicine* (2025). DOI: 10.1136/oemed-2025-110057
Journal information: Occupational and Environmental Medicine
Provided by British Medical Journal

MAY 21, 2025

Mind the band gap: Researchers create nanoscale forms of elementary semiconductor with tunable electronic properties

by University of Nottingham edited by Sadie Harley, reviewed by Robert Egan



Sub-nanometer diameter control and bandgap analysis of individual selenium nanowires through electron microscopy. Credit: *Advanced Materials* (2025). DOI: 10.1002/adma.202501821

Researchers have demonstrated that by using a semiconductor with flexible bonds, the material can be molded into various structures using nano containers, without altering its composition. The discovery could lead to the design of a variety of customized electronic devices using only a single element.

Semiconductors are vital to our daily lives, as they are found in nearly every electronic device. One of the key characteristics of semiconductors is their band gap, which determines how they conduct electric current. The band gap is typically engineered for specific applications by breaking chemical bonds or introducing additional elements into the material. However, these processes can be complex and energy-intensive.

Researchers from the University of Nottingham, the EPSRC SuperSTEM facility, Ulm University in Germany, and BNNT LLC in the U.S. imaged new forms of selenium using transmission electron microscopy, employing nanotubes as tiny test tubes. The study has been published in *Advanced Materials*.

Dr. Will Cull, research fellow in School of Chemistry, University of Nottingham, who carried out the experimental work, said, "Selenium is an old semiconductor with a rich history, having been used in the first solar cells. In our research, we have revitalized selenium by discovering new forms that can emerge when confined to the nanoscale."

Selenium can exist as nanowires, with its structure and bonding varying by diameter. Below a certain size, the bonding between selenium atoms changes, increasing bond angles. This causes straightening of the initially helical structure, ultimately constricting it into atomically thin wires.

Dr. Will Cull said, "We successfully imaged new forms of selenium using transmission electron microscopy, employing nanotubes as tiny test tubes. This approach allowed us to create a new phase diagram that connects the atomic structure of selenium to the diameter of the nanowires."

Electron microscopy movies of the selenium nanowire extrusion filmed in real time. Credit: University of Nottingham
The Nottingham group previously reported using nano test tubes to image chemical reactions of individual molecules and to observe phase transitions in semiconductors. This approach enables real-time filming of chemistry at the atomic level.

Dr. Will Cull said, "To our astonishment, we observed that the nano test tube became thinner as we imaged it! Before our very eyes, we witnessed the selenium nanowire inside the nanotube being squeezed like toothpaste, stretching and thinning.

"This serendipitous discovery allowed us to establish mechanisms for the transformation of one type of nanowire to another, which have implications for their electronic properties, with near-atomic precision."

The band gap is a crucial property of semiconductors that significantly impacts their use in various devices, including solar cells, transistors, and photocatalysts. Professor Quentin Ramasse, director of EPSRC SuperSTEM, said, "By utilizing atomically resolved scanning transmission electron microscopy coupled with electron energy loss spectroscopy, we were able to measure the band gaps of individual chains of selenium. These measurements enabled us to establish a relationship between the diameter of these nanowires and their corresponding band gaps."

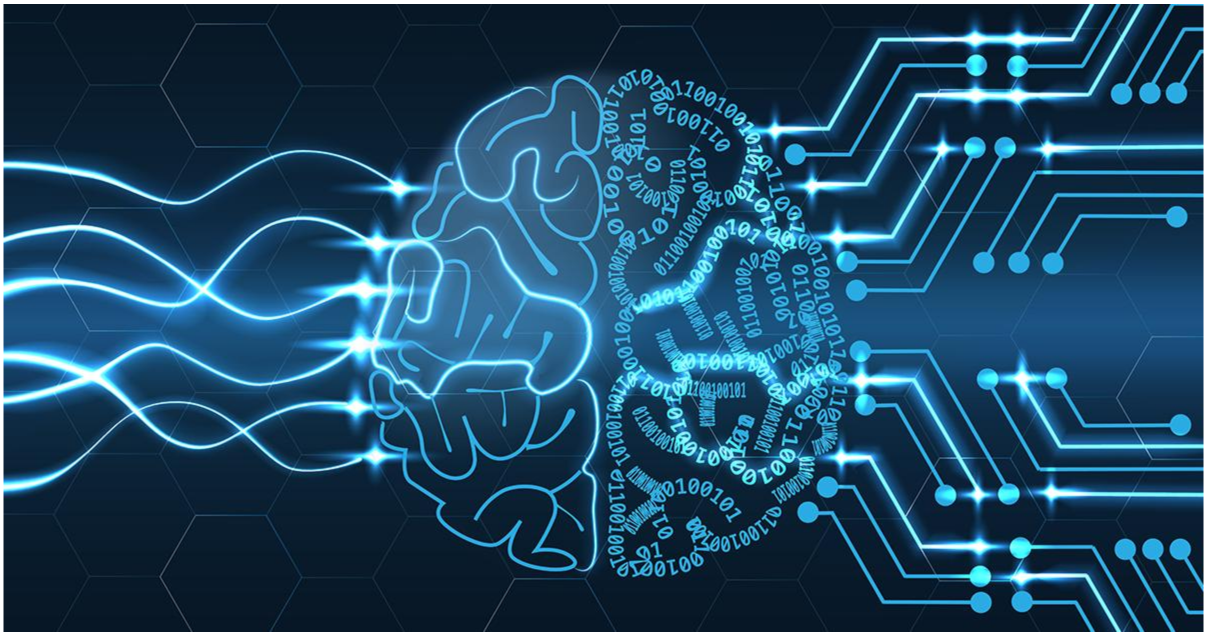
Professor Quentin Ramasse said, "Traditionally, carbon nanotubes have been used as nano test tubes; however, their outstanding energy absorption properties can obscure the electronic transitions of the material inside. In contrast, a newer type of nano test tube, boron nitride nanotubes, is transparent, allowing us to observe the band gap transitions in selenium nanowires contained within them."

The famous Moore's Law states that the number of transistors on an integrated circuit doubles approximately every two years. As a result, electronic components must become smaller.

Professor Andrei Khlobystov, School of Chemistry, University of Nottingham, said, "We have investigated the ultimate limit for nanowire size while preserving useful electronic properties. This is possible for selenium because the phenomenon of quantum confinement can be effectively balanced by distortions in the atomic structure, thus allowing the band gap to remain within a useful range."

The researchers hope that these new materials will be incorporated into electronic devices in the future. Accurately tuning the band gap of selenium by changing the diameter of the nanowire could lead to the design of a variety of customized electronic devices using only a single element.

More information: William J. Cull et al, Flexible Selenium Nanowires with Tuneable Electronic Bandgaps, *Advanced Materials* (2025). DOI: 10.1002/adma.202501821
Journal information: Advanced Materials
Provided by University of Nottingham



Researchers find human learning can be duplicated in solid matter

Researchers have found that learning — a universal feature of intelligence in living beings — can be mimicked in synthetic matter. Published Sep 28, 2021

[Sept 27, 2021: Rutgers University]
Rutgers researchers and their collaborators have found that learning -- a universal feature of intelligence in living beings -- can be mimicked in synthetic matter, a discovery that in turn could inspire new algorithms for artificial intelligence (AI). The study appears in the journal *PNAS*.

One of the fundamental characteristics of humans is the ability to continuously learn from and adapt to changing environments. But until recently, AI has been narrowly focused on emulating human logic. Now, researchers are looking to mimic human cognition in devices that can learn, remember and make decisions the way a human brain does.

Emulating such features in the solid state could inspire new algorithms in AI and neuromorphic computing that would have the flexibility to address uncertainties, contradictions and other aspects of everyday life. Neuromorphic computing mimics the neural structure and operation of the human brain, in part, by building artificial nerve systems to transfer electrical signals that mimic brain signals.

Researchers from Rutgers, Purdue and other institutions studied how the electrical conductivity of nickel oxide, a special type of insulating material, responded when its environment was changed repeatedly over various time intervals.

Rutgers researchers and their collaborators have found that learning -- a universal feature of intelligence in living beings -- can be mimicked in synthetic matter, a discovery that in turn could inspire new algorithms for artificial intelligence (AI). (Credit: Rutgers University-New Brunswick)

"The goal was to find a material whose electrical conductivity can be tuned by modulating the concentration of atomic defects with external stimuli such as oxygen, ozone and light," said Subhasish Mandal, a postdoctoral associate in the Department of Physics and Astronomy at Rutgers-New Brunswick. "We studied how this material behaves when we dope the system with oxygen or hydrogen, and most importantly, how the external stimulation changes the material's electronic properties."

The researchers found that when the gas stimulus changed rapidly, the material couldn't respond in full. It stayed in an unstable state in either environment and its response began to decrease. When the researchers introduced a noxious stimulus such as ozone, the material began to respond more strongly only to decrease again.

"The most interesting part of our results is that it demonstrates universal learning characteristics such as habituation and sensitization that we generally find in living species," Mandal said. "These material characteristics in turn can inspire new algorithms for artificial intelligence. Much as collective motion of birds or fish have inspired AI, we believe collective behavior of electrons in a quantum solid can do the same in the future.

"The growing field of AI requires hardware that can host adaptive memory properties beyond what is used in today's computers," he added. "We find that nickel oxide insulators, which historically have been restricted to academic pursuits, might be interesting candidates to be tested in future for brain-inspired computers and robotics."

The study included Distinguished Professor Karin Rabe from Rutgers and researchers from Purdue University, the University of Georgia and Argonne National Laboratory.
