BRAIN INTRACRANIAL VOL 8

Why do we dream? Neuroscientist theory suggests it's to expand our understanding of world

Overfitted brain hypothesis says dreams act as a countermeasure to routine, allowing us to learn more about the universe.

One neuroscientist suggests that the weirdness of our dreams is not a glitch in the system – it's a feature. ***Content provided by British Council***

Lizards, birds and humans have a little-known commonality: they all dream. The average person has 1,460 dreams a year, about four dreams a night. The vast majority of dreaming occurs during the rapid eye movement (REM) stage of sleep. REM sleep was first discovered 70 years ago, when researchers studying newborns noticed that their eyes moved about rapidly during sleep.

There are many theories as to why we dream. Some researchers believe that dreams play an important part in regulating our emotions. Neuroscientists

suggest that dreams play a key role in helping us store and consolidate memories. Even nightmares have benefits, according to some sleep scientists. They say these dreams can be viewed as a sort of “dry run” of sorts, the brain’s way of preparing us for the many challenging events that could come our way.

Erik Hoel, an American neuroscientist, neuro-philosopher, and author of *The World Behind The World*, a new book on consciousness and free will, has a new and novel theory of why we dream, outlined in a recent paper in the journal Patterns. His overfitted brain hypothesis (OBH) suggests that the weirdness of our dreams is not a glitch in the system – it’s a feature. Hoel thinks dreams occur to make our understanding of the world less simplistic and more expansive. Our dreams’ peculiarity acts as a sort of countermeasure against the routine experiences of everyday life.

Hoel’s OBH was inspired by machine learning, a process that involves using large data sets to train algorithms. “Overfitting” is a term straight out of the machine learning dictionary. In simple terms, it is a statistical modeling error that occurs when a function finds itself curtailed by a narrow set of data points: it can’t process an answer if there is insufficient data from which to extrapolate.

One way of counteracting overfitting is through data augmentation, a process that allows a user to increase the amount of data by essentially generating new data points from data already in place. Our dreams, if Hoel’s theory is to be believed, involve some sort of brain-based data augmentation. His OBH theory also suggests that the purpose of dreaming is to improve learning by reducing overfitting. The theory developed after he used a form of qualitative research that looked in-depth at non-numerical data – interviews and observation notes – to study people’s conscious experience while dreaming. He noticed the process was similar to the techniques that machine learning researchers used to improve the flexibility and generality of their artificial intelligence (AI) models.

As for testing his hypothesis, Hoel did concede that scientifically scrutinizing a theory in neuroscience “is always quite difficult”. That’s because neuroscience is not really at a point where we can conclusively prove that an idea is false. Hoel argues that evolution itself invented fiction hundreds of millions of years ago in the form of dreams.

“Dreams are biologically created fictions. So if you can figure out why evolution invented dreams, you can figure out why humans pay so much attention to fictions … I think dreaming is probably, over the course of a lifetime, extremely important for sculpting the generality of our learning, and for keeping us from becoming too trained or specialized to one type of thing”.

Why do we dream? Science of sleep and what happens when we don’t get enough

Scientist Sigmund Freud suggested dreams had hidden meanings, while psychiatrist Carl Jung said they were reflections of our minds. No single theory can fully explain dreams, but we do know they are closely related to the stages of sleep

Dreams are a fascinating mystery – whether it is a terrifying nightmare or a vivid fantasy, most of us can still vividly recall at least one. Songs have been composed and scientific discoveries realized during sleep. But why do we dream? And how do these visions come alive in our brains?

Why do we dream?

We still do not know a lot about dreams, but many have proposed theories to explain them. Austrian scientist Sigmund Freud – who is the founder of psychoanalysis, a method of treating mental disorders – suggested that dreams had hidden meaning and came from desires that we pushed away. Meanwhile, Swiss psychiatrist Carl Jung said dreams were reflections of our minds and could reveal future life developments.

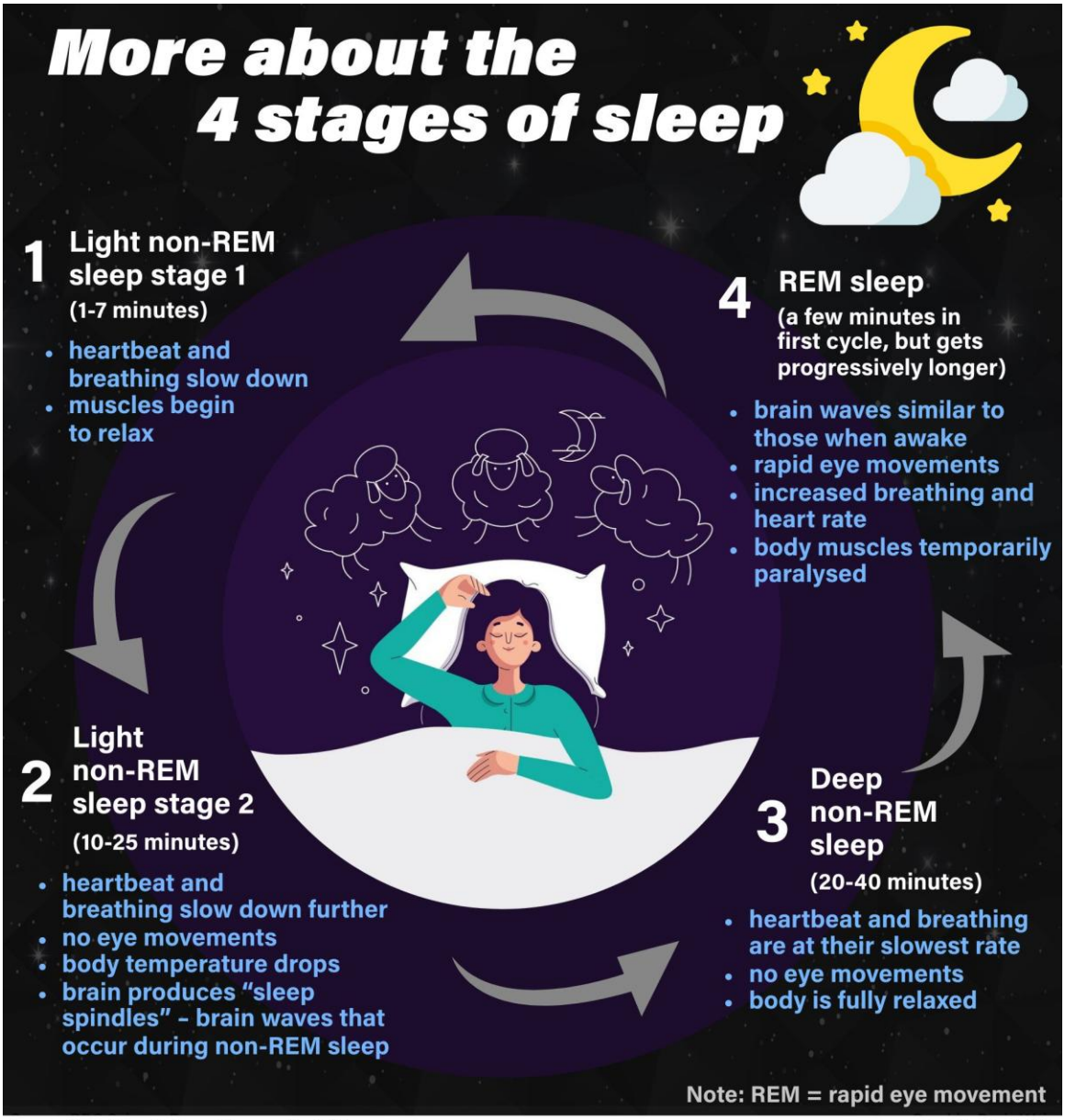
Later on, sleep scientists Allan Hobson and Robert McCarley said dreams happened as the brain tried to make sense of the random signals it received in sleep. Other theories suggest that dreams are a rehearsal of real-life events that help us cope with stress. Research has found that as we dream, the brain finds meaningful patterns while getting rid of unhelpful “background noise”, which could help in problem-solving. No single theory can fully explain dreams, but we do know that they are closely related to the stages of sleep.

Four stages of sleep

There are four stages of sleep: light non-rapid eye movement (REM) sleep stages 1 and 2, deep non-REM sleep, and REM sleep. We cycle through these stages several times throughout the night (see graphic).

Non-REM sleep consists of three parts: falling asleep, light sleep and deep sleep. During this time, brain waves slow down, and muscles slowly relax.

Each night, we spend about two hours dreaming, most of which happens during REM sleep. During this stage, our brain waves are active, and our eyes move rapidly.



Source: Hong Kong Science Museum; Healthline

Graphic: Doris Wai

But muscles experience temporary paralysis. This paralysis is caused by neurotransmitters – chemicals carrying messages between nerve cells – that stop us from physically acting out our dreams and potentially hurting ourselves.

But why do our dreams feel so real? When we sleep, the activity of the prefrontal cortex of our brain – which controls our rational judgment – decreases. But REM sleep increases the activity of the visual cortex, which controls what we see, and the amygdala, which controls emotion.

What happens when sleep cycle is disrupted

If we wake up during the first stage of non-REM sleep, we may be unaware we have been sleeping. But if we wake up in the middle of the non-REM deep sleep stage, we might feel confused and sleepy.

Some people experience a phenomenon called sleep paralysis if their sleep cycle is disrupted. When this happens, they feel as if they are conscious but cannot move. Other common symptoms of sleep paralysis include feeling like you cannot breathe or speak.

Sleep paralysis happens when we regain awareness while going into or coming out of REM sleep. Even though it feels like we are awake, we cannot move because our motor neurons are temporarily inhibited. This often happens alongside the vivid dreams during REM sleep.

Scientists are still working to unravel the mystery of dreams, but until then, good night, and sweet dreams!

Young Post is pleased to partner with Hong Kong Science Museum and Hong Kong Space Museum on our STEM Lab series. Our aim is to encourage you in your pursuit of science. Every month, the two museums will answer your burning questions about the fantastic world around us, the cosmos, and beyond.

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SPU 科學推廣組 Science Promotion Unit

What dreams are made of: Scientists mine sleep's mysteries

For millennia, people have been fascinated by dreams.

"What a weird and wondrous experience it is that we get thrown into these virtual worlds where we meet people, we interact with them, where we can feel all kinds of emotions," Antonio Zadra, a sleep and dream researcher at the University of Montreal, framed it in a recent interview.

Today, researchers continue to look for answers to how and why we dream, as growing evidence links dreaming to our health.

In the late 1800s, scientists began to interrogate the neurological basis of dreams. In 1893, psychologist Mary Calkins led a sleep study by candlelight, rousing the participants — one man, one woman — throughout the night to ask whether they were dreaming and to describe the vividness of their dreams.

From Calkins to Freud

Calkins was the first to quantify elements and timing of dreams.

She found that dreams generally took place in the present, and "when the dream was of the childhood's home, or of some person who had not been seen for many years, the apparent age of the dreamer was never lessened to avoid anachronism. … It is thus evident that the dream is connected with the waking life, and — in the experience of these observers — usually with the recent life."

But shortly after Calkins's work, interest shifted to what dreams meant, Zadra said, at least in part because of Sigmund Freud.

Starting around 1900, the founder of psychoanalysis presented dreaming in the context of repressed desires. Freud wrote, for instance, that some anxiety dreams originate "in psychosexual excitation, in which case, the anxiety corresponds to repressed libido." And, if someone dreamed of a still-living family member dying,

Freud believed "the dreamer has wished them dead at some time or other during his childhood."

Interest shifted back with the 1953 discovery of rapid eye movement (REM) sleep and the subsequent observation that when people are awakened from REM, they often have vivid dream recall. Research since then has shown that dreaming can happen during many stages of sleep. Even people who have brain lesions or take medications that all but eliminate REM still dream.

A wandering mind

Although certain electrical activity patterns in the brain have been linked to the presence or absence of dreaming, there is still no definitive biomarker signaling that a person is dreaming. Over the past decade, increased attention has been paid to the default mode network — a group of brain regions that become active when a person's mind wanders, for example, while gazing out a window.

"Many of the more recent models of why we dream are tied into dreams as an intensified form of mind wandering," Zadra said. But why we dream is still a point of contention in the field.

One long-held hypothesis is that dreaming serves as a means of simulating potential threats, preparing us for danger that may come our way.

"But many, many dreams have no physical or psychological threats," Zadra countered. He said he thinks we dream to make sense of our waking experiences in the context of our past, drawing in loosely associated connections — something the default mode network allows us to do.

"When you wake up, things have been integrated into your understanding of yourself, of the world, your place in it, in bizarre, unrelated ways," he said. "And what does that help you do? It helps you predict, or better, adapt to what lies ahead."

Emotional processing

Another leading explanation is that it helps us process and regulate our emotions.

Sara Mednick, a cognitive scientist at the University of California at Irvine, said she views dreams as a "safe space where we can bring up potentially emotionally charged experiences," and then play out the possibilities. "What you see is increases in arousal during dreams, but then you also see a calming down of that arousal system during the dream time," she said.

In her research, Mednick has found that, for people who have experienced a negative emotional event, dreaming about it can help tamp down the attached emotions.

"If you dream about an event, you will retain detailed memory for that event, but you will also, across time, have less of an emotional arousal when you think about that event," she said.

Mednick also views dreams as a kind of "overnight therapy," citing a sleep study that found, among divorced people, those who dreamed about their ex-spouses had fewer depressive symptoms after one year. It illustrates that dreaming can have "nice long-term implications for having a healthy relationship with your emotional past," she said.

Insights from dreaming

But some people go through life never remembering a dream. In sleep studies where participants are roused every five minutes throughout the night, they might report having dozens of dreams, and so a person who experiences micro-awakenings throughout the night might recollect more of their dreams.

Interest in a dream can also influence whether you remember it, said Zadra, as can waking up without an alarm.

"If you wake up naturally, then there's a higher chance that you will wake up from REM sleep," said Jing Zhang, a cognitive scientist at Harvard Medical School and Massachusetts General Hospital. Waking up during REM increases your odds of

being in the midst of a dream. Zhang suggested writing down dreams you remember as soon as you wake up, as studies show that doing so improves dream recall.

Dreams can provide insight into a person's well-being.

People who are more stressed or anxious "have more negative dreams and more negative dream content," Zadra said. "They have more aggressive interactions in the dreams than friendly interactions. They have more hostilities, they have more failures than success. But as a person's well-being improves, there are corresponding changes in their dream content."

"A lot of [people with] mood disorders — depression, anxiety, PTSD — they report different patterns of dreaming, where they have excessive dreams," which may be the result of prolonged REM, said Zhang, who is starting to investigate the role of dreaming in psychiatric populations, particularly people with schizophrenia.

If someone with PTSD is experiencing nightmares on replay, "they have a worse prognosis in terms of PTSD symptoms. It's an indication that the system isn't adapting as well as it could," Zadra said. But this can be reframed as an opportunity for someone to seek help. "They need therapy, they need medication, they need something," he added.

Dreaming is something all of us do, to different extents. Some of us have vivid dreams that we can recall perfectly the next morning and the rest of us find ourselves trying to remember more than vague details of what happened during our slumber.

Why we do this is still not something that scientists can agree wholeheartedly on, and, while there isn't a conclusive answer at this point, a new theory that was published this year might just be the answer we've been looking for.

Dreams could be serving as a function

Writing for the British Psychological Society, Mark Blagrove said that while there are theories as to what happens when we dream, the purpose of them could actually be far more related to our waking life.

This is especially true when it comes to telling others about our dreams.

Blagrove said: "Dream-sharing may increase empathy because the dream acts as a piece of fiction, which is explored by the dreamer and others as part of the sharing process.

"Dreams would thus be like literary fiction, which has itself been shown to elicit empathy towards the characters that the fiction describes."

Blagrove and his team have found that sharing what happens in our dreams opens the door for being more vulnerable and open with people. He said: "We suggest that the function of dreams thus resides in their waking use, and that dreams are like blushing, a way for self-disclosure to be supported, for the benefit of the group, even if such self-disclosure can sometimes be uncomfortable for the individual."

This makes sense to me. There have been times that I've described particularly overwhelming dreams to loved ones just to later disclose that I was likely dreaming about such disturbing things because I was struggling with the pressures and stresses of my waking life.

This is just a theory for now but hopefully we'll learn more from Blagrove and his team soon.

Sleep 'cleans' the brain of toxins

The brain uses sleep to wash away the waste toxins built up during a hard day's thinking, researchers have shown.

The US team believe the "waste removal system" is one of the fundamental reasons for sleep.

Their study, **in the journal Science, external**, showed brain cells shrink during sleep to open up the gaps between neurons and allow fluid to wash the brain clean.

They also suggest that failing to clear away some toxic proteins may play a role in brain disorders.

One big question for sleep researchers is why do animals sleep at all when it leaves them vulnerable to predators?

It has been shown to have a big role in the fixing of memories in the brain and learning, but a team at the University of Rochester Medical Centre believe that "housework" may be one of the primary reasons for sleep.

"The brain only has limited energy at its disposal and it appears that it must choose between two different functional states - awake and aware or asleep and cleaning up," said researcher Dr Maiken Nedergaard.

"You can think of it like having a house party. You can either entertain the guests or clean up the house, but you can't really do both at the same time."

Plumbing

Their findings build on last year's discovery of the brain's own network of plumbing pipes - known as the glymphatic system - which carry waste material out of the brain.

Scientists, who imaged the brains of mice, showed that the glymphatic system became 10-times more active when the mice were asleep.

Cells in the brain, probably the glial cells which keep nerve cells alive, shrink during sleep. This increases the size of the interstitial space, the gaps between brain tissue, allowing more fluid to be pumped in and wash the toxins away.

Dr Nedergaard said this was a "vital" function for staying alive, but did not appear to be possible while the mind was awake.

She told the BBC: "This is purely speculation, but it looks like the brain is losing a lot of energy when pumping water across the brain and that is probably incompatible with processing information."

She added that the true significance of the findings would be known only after human studies, but doing similar experiments in an MRI machine would be relatively easy.

Commenting on the research Dr Neil Stanley, an independent sleep expert, said: "This is a very interesting study that shows sleep is essential downtime to do some housekeeping to flush out neurotoxins.

"There is good data on memory and learning, the psychological reason for sleep. But this is the actual physical and chemical reason for sleep, something is happening which is important."

Dr Raphaelle Winsky-Sommerer, a lecturer in sleep at Surrey University, said: "It's not surprising, our whole physiology is changing during sleep.

"The novelty is the role of the interstitial space, but I think it's an added piece of the puzzle not the whole mechanism.

"The significance is that, yet again, it shows sleep may contribute to the restoration of brain cell function and may have protective effects."

Many conditions which lead to the loss of brain cells such as Alzheimer's or Parkinson's disease are characterised by the build-up of damaged proteins in the brain.

The researchers suggest that problems with the brain's cleaning mechanism may contribute to such diseases, but caution more research is needed.

The charity Alzheimer's Research UK said more research would be needed to see whether damage to the brain's waste clearance system could lead to diseases like dementia, but the findings offered a "potential new avenue for investigation".

Your consciousness could travel the multiverse when you dream, claim scientists

Your consciousness could travel multiverse when you dream, claim scientists

Scientists have suggested that dreams sometimes act as portals to alternate realities, connecting a person to another version of themselves in a parallel world.

"Dreams have been historically perceived as mirrors reflecting our conscious waking life, laden with symbolic representations of our desires, fears, and experiences," they claimed in their research article.

"Conversely, a riveting conjecture exists that dreams might also function as conduits to alternative dimensions or elevated states of consciousness, suggesting a more profound and expansive role than traditionally conceived," they added.

This hypothesis takes inspiration from the "many worlds interpretation of quantum theory," which is sometimes also referred to as the multiverse theory.

It suggests that for a quantum event, there are multiple possibilities or outcomes. Each of these outcomes plays out in separate universes. So, for example, if you played a football match, your team may have won in this universe, but in some other universe, your team may have lost the game.

The authors suggest that in dreams, one can travel to these other universes. However, this isn't the the primary scientific basis they used to support their hypothesis.

Can dreams overcome physical limits?

According to David Leong, who is the first author of the article and an honorary professor at Charisma University in Turks and Caicos, when a person sleeps and dreams, it might be possible his consciousness crosses the boundaries of space and time.

This is because, during sleep, a person's consciousness is in the least contact with his logical brain, reality, and physical senses. Notably, scientists still don't know much about human consciousness, and its limitations.

It is possible consciousness also experiences something like quantum entanglement — a phenomenon that suggests that two particles can affect each other's states irrespective of the distance between them.

It might be possible that consciousness is also capable of affecting people across parallel universes. "This leads to a re-conceptualization of consciousness as a

more expansive and interconnected entity with the potential to navigate a multiverse of experiences," the authors said.

Moreover, different versions of a person might have a shared collective unconscious, a concept proposed by psychologist Carl Jung in the early 1900s. Jung used this concept to refer to a part of the mind shared by all humans, containing instincts, memories, and ideas that are passed from one generation to another.

"Dreams could be the psyche's means of tapping into this collective unconscious, exploring and experiencing the shared human narrative that extends beyond the personal," the research article added.

However, these are all possibilities and there is no real empirical evidence confirming that a person can indeed travel to alternate realities in dreams.

Not all dreams take you to the multiverse

Leong suggests that recurring vivid dreams with strong emotions and memories are the ones that can probably take people to their alternate versions in parallel worlds.

"Say you have a repetitive dream of being stuck in high school. While it may reflect unresolved psychological themes, such as feelings of stagnation or anxiety about personal growth, it could also indicate that in another reality, you are still in high school, dealing with the same challenges your waking self has moved beyond," remarked Leong, as reported by *Popular Mechanics*.

Meanwhile, other dreams that a person experiences might still be the result of their subconscious mind's perception of the memories, experiences, fears, emotions, and desires they have.

For now, there's no way to prove whether the proposed hypothesis is right. However, recurring dreams with vivid imagery and strong emotional resonance may warrant further examination, as they could potentially offer clues about experiences in alternate realities.

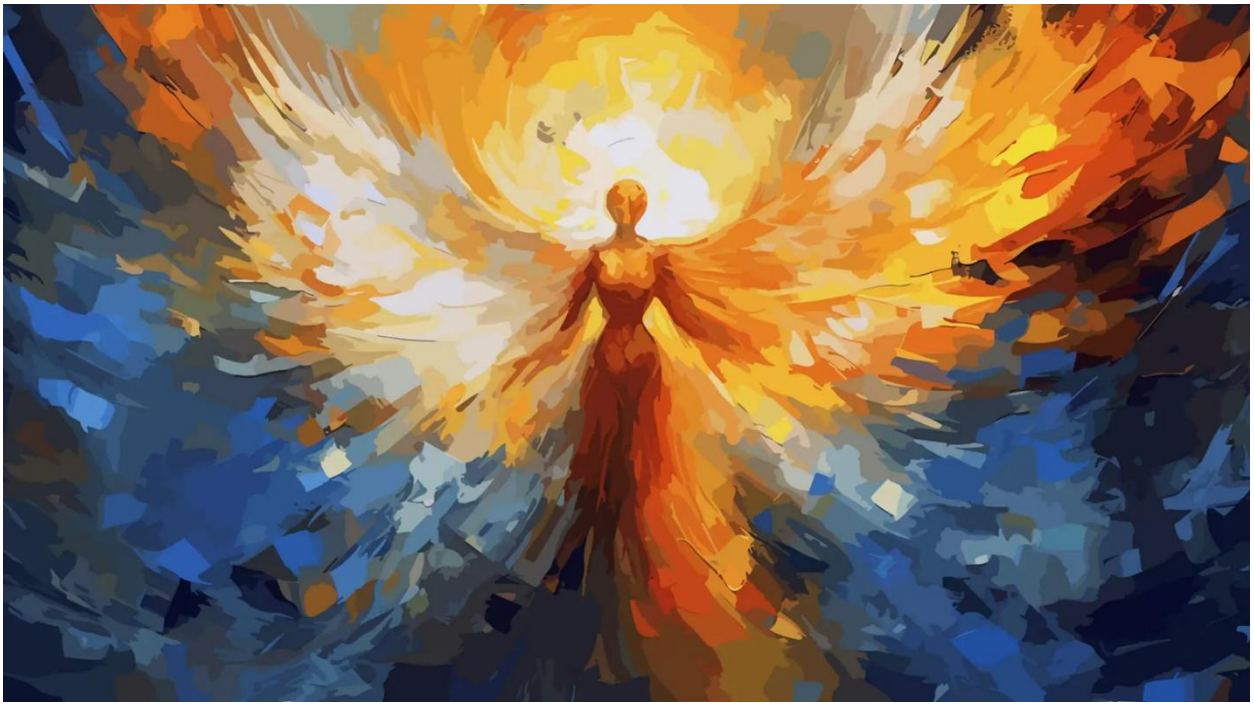
The research article is published in *Qeios*.

Are dreams truly a gateway to the subconscious?

Do dreams send us important messages from our deepest selves? Why do some dreams stay with us, vivid as day, while others slip away? Neuroscientists and psychologists have endeavored to answer these questions for decades, with fascinating results.

From the historical and cultural tapestries that have shaped our understanding of dreams to the cutting-edge scientific discoveries revealing what happens in our brains at night, this gallery is a journey through the night's most profound mystery.

Are you ready to explore the hidden corridors of your own mind? Click through to unravel the secrets that await in the world of dreams.



Historical perspectives on dreams

Historically, dreams were seen as divine messages or omens. This evolution from ancient beliefs to today's scientific understanding reflects our growing knowledge of brain science and psychology.

The physiology of dreaming

During REM sleep, the brain becomes highly active, similar to when awake. This stage is critical for dreaming, involving areas like the amygdala for emotions and the hippocampus for memories.

The REM cycle and Its importance in dreaming

REM sleep, a cycle occurring every 90 minutes during sleep, is crucial for consolidating memories and processing emotions, often resulting in intense dreaming.

Why do we dream? Theories and insights

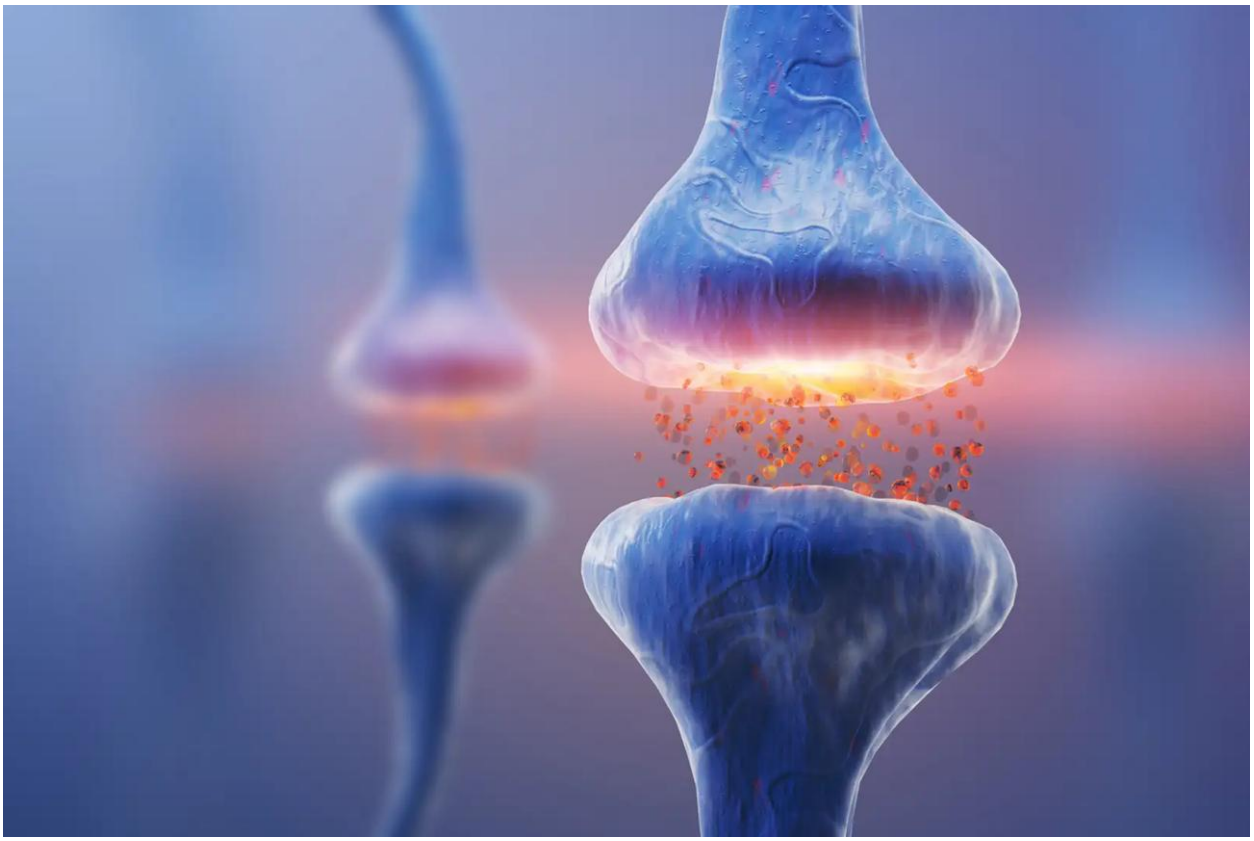
Scientific theories suggest dreams aid in emotional regulation, problem-solving, and consolidating learning and memories. Psychologists propose they reflect our unconscious mind and inner conflicts.

Dreams and the subconscious mind

Dreams are a gateway to our subconscious, revealing hidden fears, desires, and conflicts. This connection highlights how dreams can be a tool for psychological insight and self-awareness.

The role of dreams in memory consolidation

Dreams play a critical role in solidifying memories. During sleep, the brain reorganizes and integrates new information with existing knowledge, a process vividly reflected in our dreams.

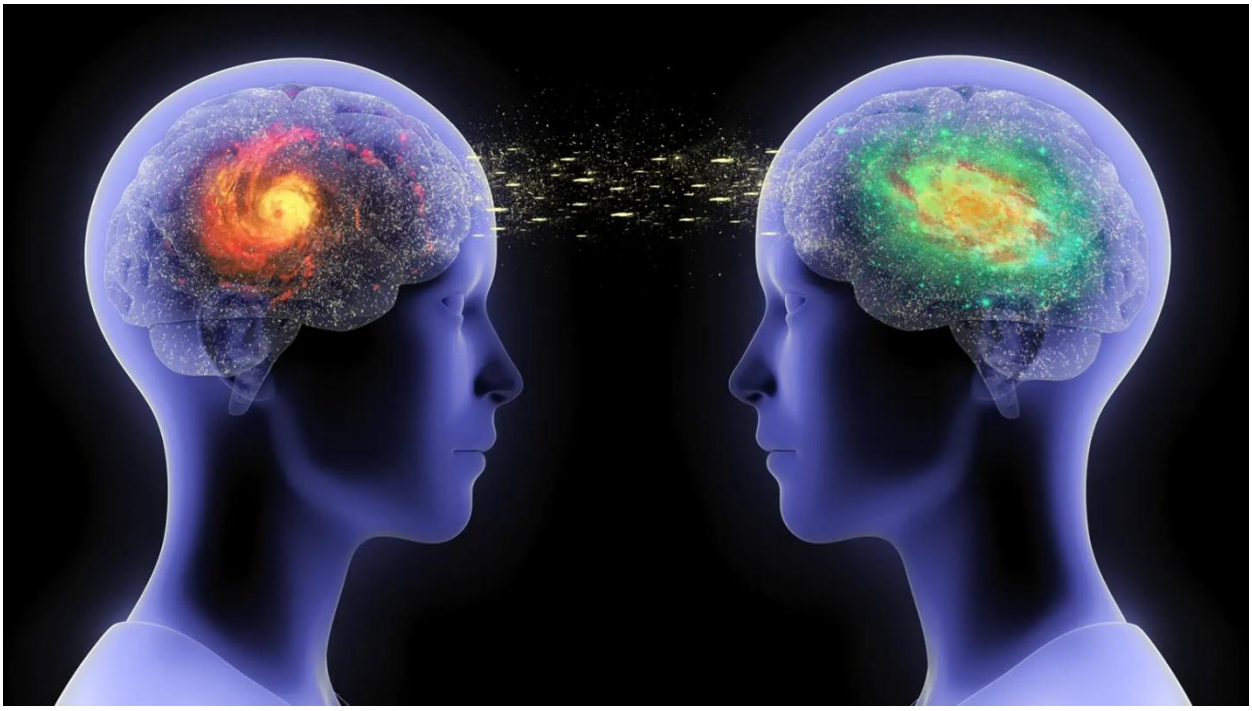


Neurological mechanisms behind dreaming

Dreaming involves various brain regions, including the prefrontal cortex, which is less active, leading to illogical dream scenarios. Neurotransmitters like serotonin and norepinephrine are also at play.

The link between dreams and emotional processing

Dreams are essential for emotional health, allowing the brain to process and interpret emotions experienced during waking hours, often leading to psychological resolution and understanding.



Dreams in different cultures and their interpretations

Across cultures, dreams have been interpreted differently, from prophetic visions to messages from ancestors. This diversity reflects the universal, yet culturally unique, nature of dreaming.

Why some remember dreams and others don’t

Dream recall varies; some remember vividly while others can barely recall any details. This difference is influenced by factors like sleep quality, stress levels, and even genetic predispositions.

Understanding nightmares and their causes

Nightmares, often stress or trauma-induced, are a brain mechanism to process and cope with fears. They can also result from sleep disorders or medications.

Vivid dreams: what makes them different

Vivid dreams are marked by intense, lifelike experiences. Factors like stress, sleep deprivation, and certain medications can trigger these extraordinarily clear dreams.

Dreams and mental health

The content and nature of dreams can reflect one's mental health. Recurrent themes or disturbing dreams might signal underlying psychological issues.

Lucid dreaming: gaining control within dreams

Lucid dreaming is a state where the dreamer is aware they're dreaming and can sometimes control the narrative. This phenomenon illustrates the brain's remarkable capability for self-awareness during sleep.

Interpreting common dream themes and symbols

Common dreams, like falling or flying, carry universal symbols but can have unique meanings based on the individual's experiences and emotions.

Impact of external stimuli on dream content

External noises or sensations can infiltrate our dreams, demonstrating how our sleeping brain processes real-time environmental cues.

Exploring the mysteries of sleep paralysis

Sleep paralysis, a state of being conscious but unable to move, is often accompanied by vivid hallucinations. This phenomenon highlights the complex relationship between sleep stages and brain activity.

Dreams in children vs. adults

Children's dreams often feature imaginative content and evolve as they age, reflecting their developing brains and cognitive abilities.

Sleep disorders and their effect on dreaming

Disorders like insomnia or sleep apnea can significantly impact dream patterns and quality, often leading to less REM sleep and fewer remembered dreams.

Technology in dream research

Advances in neuroimaging and AI have revolutionized dream research, allowing deeper insights into the dreaming brain and its functions.

The role of dreams in problem-solving and decision-making

Dreams can contribute to problem-solving by providing creative solutions or new perspectives, often leading to 'eureka' moments upon waking.

Dreams and creativity

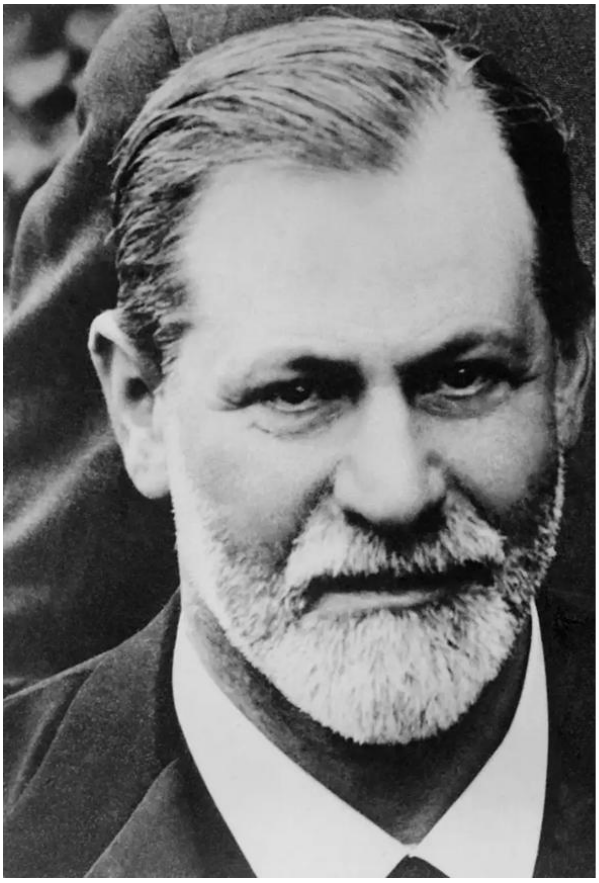
Dreams can be a source of creative inspiration, providing unique, uninhibited perspectives that have influenced artists, writers, and inventors throughout history.

Dreams and their role in cultural mythology

Across various cultures, dreams have been revered as prophetic tools or spiritual guides, deeply embedded in mythologies and religious practices.

The future of dream research and potential discoveries

As research progresses, we anticipate new discoveries about dream functions, their impact on mental health, and potential therapeutic uses.

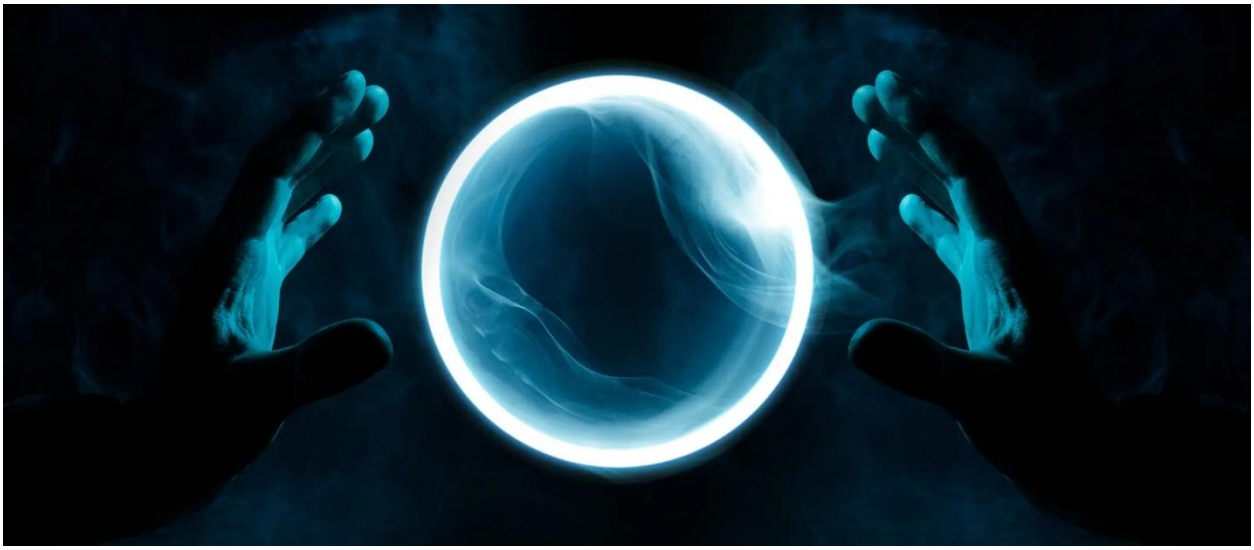


Comparing dream theories: Freud vs. Jung

Freud's and Jung's theories offer contrasting views. Freud's emphasize unconscious desires and Jung's focus on archetypes and the collective unconscious.

The effects of medication and substances on dreaming

Certain medications and substances can alter dream patterns, intensify dreams, or even suppress REM sleep, showing the chemical influence on dreaming.



Dreams and predictions: separating myth from science

While some cultures believe in prophetic dreams, science views them as reflections of the mind's inner workings rather than predictors of the future.

Personal dream journals: tools for self-discovery

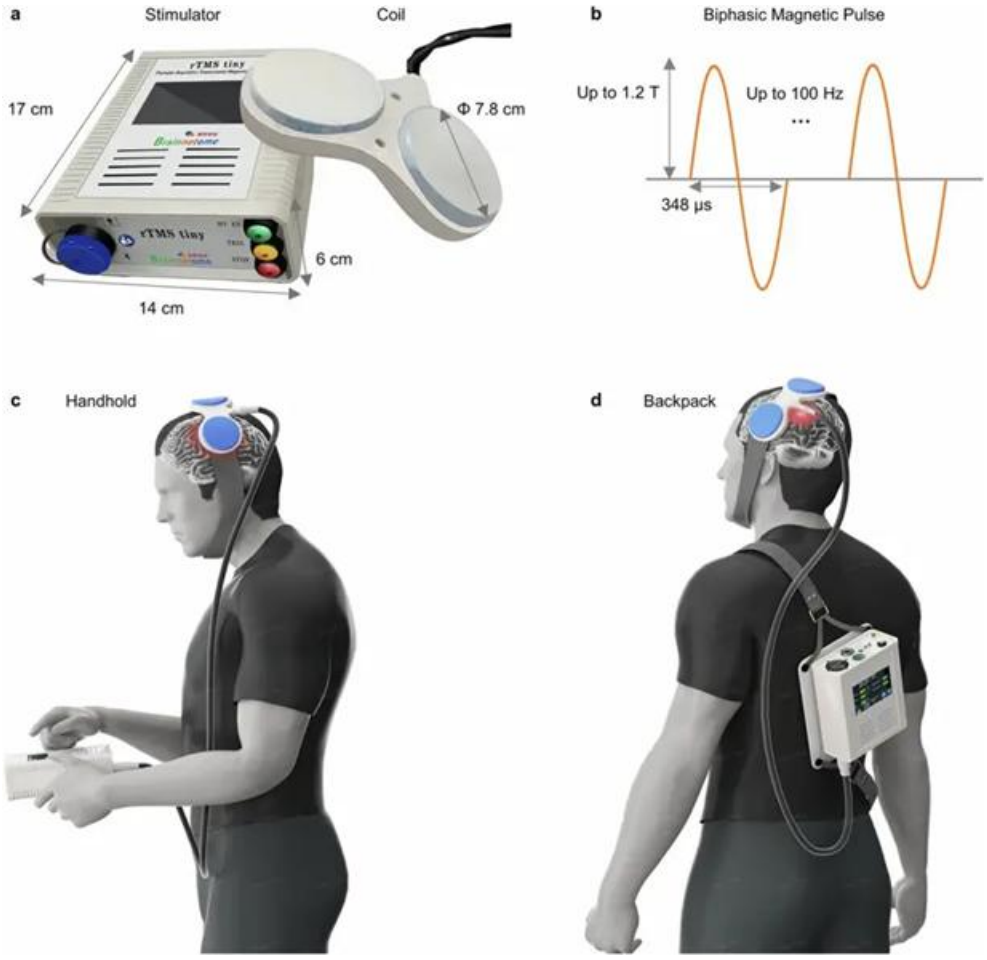
Keeping a dream journal can aid in understanding recurring patterns, themes, and emotional undercurrents, offering personal insights and self-awareness.

The ever-evolving understanding of dreams

As research continues, our understanding of dreams grows, revealing more about this fascinating intersection of science, psychology, and culture.

Sources: (Scientific American) (Knowable Magazine)

Wearable brain stimulation device could make on-the-go therapeutics a reality



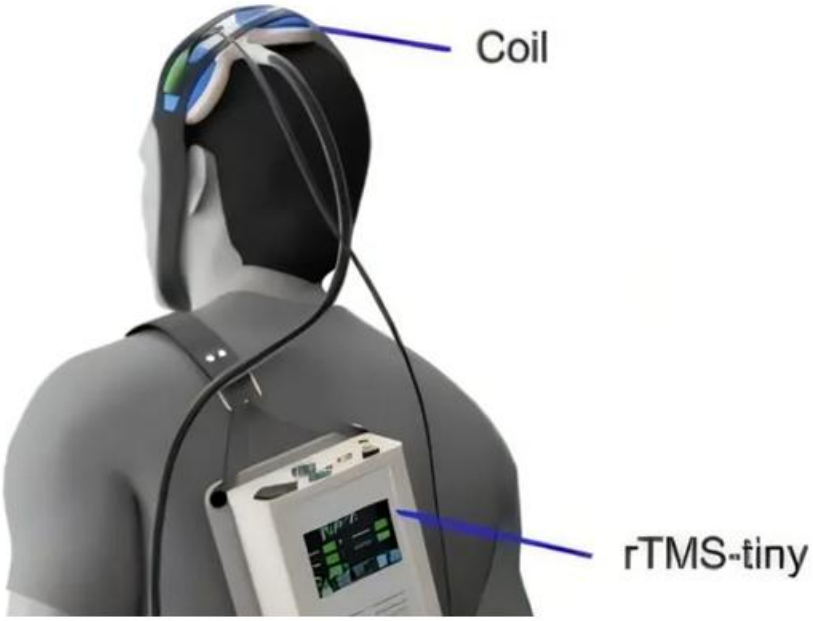
Comprehensive illustration of the wearable rTMS device. Credit: Nature Communications (2025). DOI: 10.1038/s41467-025-58095-9

Researchers at the Institute of Automation of the Chinese Academy of Sciences have developed a compact, battery-powered brain stimulation device capable of delivering therapeutic magnetic pulses while a person is walking or performing everyday activities.

Repetitive transcranial magnetic stimulation is used to treat conditions such as depression, stroke-related motor impairment, and other neuropsychiatric disorders. It is also used in cognitive and motor function research.

Existing systems need to be plugged into a power supply and have bulky designs meant for stationary use in clinical settings. These limitations prevent stimulation during natural movement, such as standing and walking, making at-home or on-the-go treatments impractical.

Investigations into how brain activity changes in dynamic environments remain incomplete because current devices cannot be used during free behaviors. Patients undergoing treatment must attend daily hospital visits over extended periods, which affects adherence and increases cost. No battery-powered or wearable system has previously achieved the intensity levels needed to trigger direct neuronal responses in the brain.



The T2-Bent-D63 coil was securely fastened to the M1 hand motor area using an elastic band, ensuring that the coil remained in close contact with the head and in a stable position. The rTMS-tiny stimulator and wireless EMG measurement equipment were carried on the back. Credit: Nature Communications (2025). DOI: 10.1038/s41467-025-58095-9

In the study, "A wearable repetitive transcranial magnetic stimulation device," published in *Nature Communications*, researchers developed and tested a portable brain stimulation system by combining lightweight coil engineering with high-voltage pulse technology to enable therapeutic stimulation during natural human movement.

A total of 15 healthy adults between the ages of 25 and 40 participated in a human testing phase.

Researchers began by designing a head-mounted coil capable of producing strong magnetic fields while using only battery power. Traditional systems rely on high-voltage electricity from the grid, generate high heat, and weigh too much for wearable applications. To address this challenge, the team engineered a novel compact figure-8 coil using specialized magnetic core materials that enhance the magnetic field while reducing energy requirements.

A control and power unit, weighing just over a kilogram, was secured across the back using shoulder straps. A high-power converter was built in to deliver pulses of up to 1,600 volts and 500 milliamps using an 18-volt battery. The unit recovered energy after each pulse to extend battery life and limit heat generation.

The coil was mounted onto the heads of participants using a padded elastic strap that wrapped under the chin for stability. This made the entire system wearable without restricting normal standing or walking movements.

Tests included simulations of electric field strength in human head models and comparisons with a commercial device. Pulse width, magnetic flux intensity, temperature rise, and repetition rates were all measured and compared to conventional systems.

Human testing followed the technical validation with participants receiving magnetic stimulation to their motor cortex while seated and while walking. To verify that the brain was responding, motor-evoked potentials were recorded from muscles in the hands and legs to confirm that the magnetic pulses reached motor areas of the brain.

In walking conditions, muscle responses more than doubled in amplitude compared to those measured at rest. These results confirmed that the device delivered effective stimulation even during natural movement.

Magnetic pulses generated by the wearable coil reached 1.2 Tesla with a pulse width of 348 microseconds, comparable to commercial brain stimulation systems. The system operated at frequencies up to 100 Hz and supported standard stimulation protocols including 10 Hz and theta burst patterns.

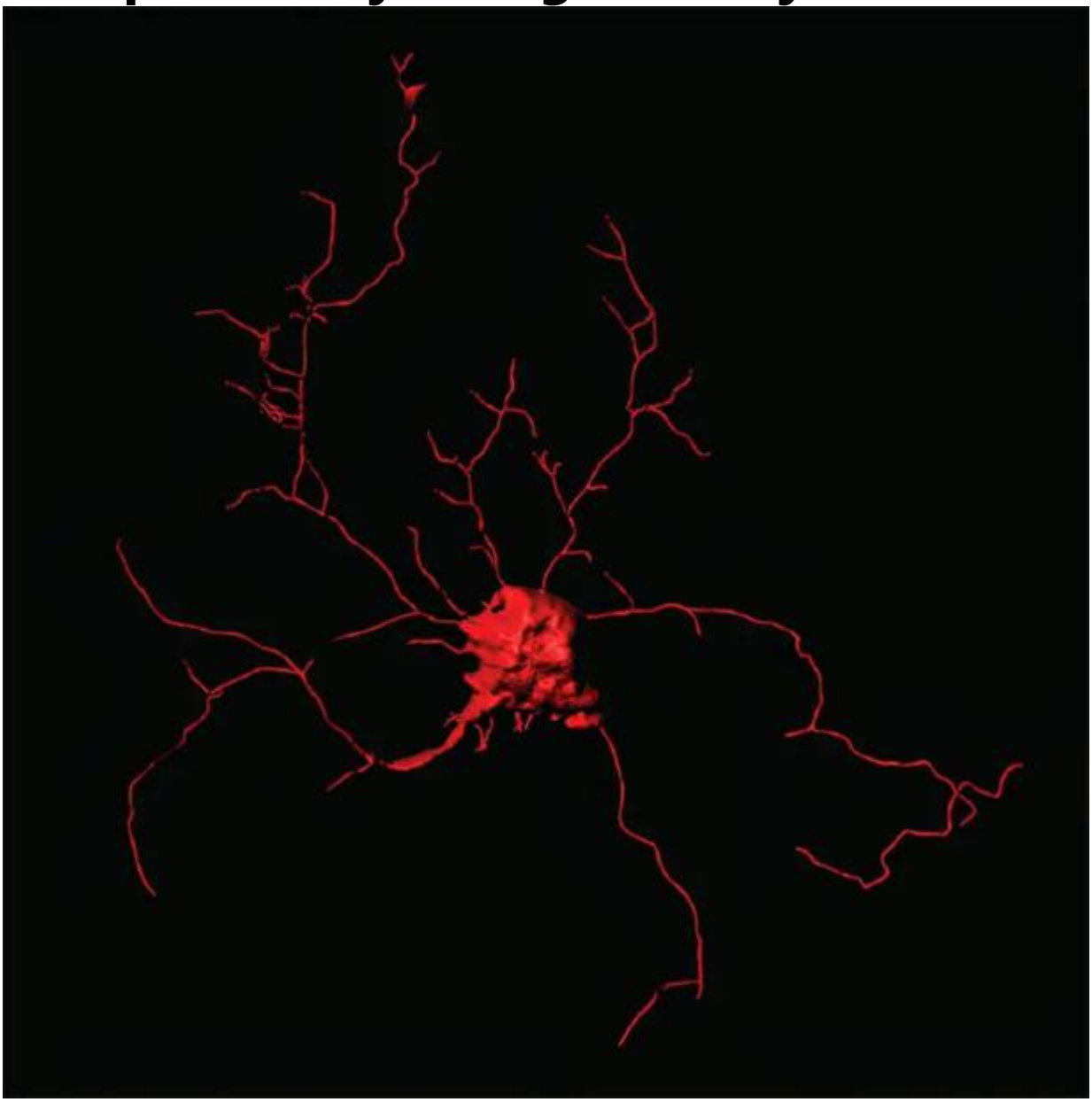
Battery-powered operation allowed delivery of over 8,000 pulses at moderate intensity on a single charge. Coil temperatures remained below safety thresholds defined by international medical device standards during high-frequency use. Infrared imaging showed uniform heat distribution, and no overheating occurred even after extended sessions.

While all testing was conducted in controlled laboratory settings, the authors propose that future versions of the device may support home-based or mobile use, pending further development of safety protocols and remote supervision systems.

Plans for future use include integration with brain-monitoring systems to allow real-time feedback and adaptive stimulation, which could support closed-loop therapeutic applications.

More information: Zihui Qi et al, A wearable repetitive transcranial magnetic stimulation device, *Nature Communications* (2025). DOI: 10.1038/s41467-025-58095-9

Brain cells are more plastic than previously thought, study shows



A computer rendering of a parvalbumin-positive neuron, which researchers were able to produce in large quantities for the first time in in-vitro models. Credit: iScience (2025). DOI: 10.1016/j.isci.2025.112295

Neurons are the cells in the brain responsible for sending messages to the rest of the body, and scientists have long thought that they are settled into one subtype once they develop from stem cells, no matter what is happening in the environment around them.

New research from the Braingeneers, a collaborative group of researchers from UC Santa Cruz and UC San Francisco, reveals that this traditional way of thinking about the fate of neurons may not be true.

A paper published in the journal *iScience* reports on the project, which reflects the Braingeneers' expertise in using cerebral organoids—3D models of brain tissue—to learn about the mysteries of brain development. Their insights can help scientists learn more about how subtypes of neurons impact neurodevelopmental conditions and the overall function of the brain.

Continue reading

"This goes against this idea that neuronal identity is completely stable," said Mohammed Mostajo-Radji, a research scientist at the UC Santa Cruz Genomics Institute and the paper's lead author. "It's making all of us rethink how neurons are actually made and maintained, and the influence of the environment in this process."

First-of-their-kind models

There are two main types of neurons in the cerebral cortex, the outermost layer of the brain: excitatory, which make up 80% of neurons, or inhibitory, the remaining 20%. Of inhibitory neurons in the cerebral cortex, the majority (60%) are parvalbumin-positive neurons.

These inhibitory cells have control over plasticity in the brain, affecting the time period in which a person has the ability to learn a new language without an accent, or enhance other senses after the loss of one. They are also recognized to be involved in many neurodevelopmental disorders, including autism and schizophrenia.

This paper shows that the scientists were able to create a large number of parvalbumin-positive neurons in the living models in the lab, the first instance when scientists were able to produce more than just a small number of these cells. These brain cells were transplanted into and cultured within cerebral organoids, and the researchers believe the 3D structure, which more closely mimics the brain, may have been key to the breakthrough.

"I think part of the answer is that it does not work if you try 2D models," Mostajo-Radji said. "We provide what I believe is the first evidence that you need a 3D environment. It might challenge us to think about what other cell types we still can't make in-vitro, and if that's because we always thought everything could be done in 2D, but actually they need a 3D environment."

The ability to produce and maintain these parvalbumin-positive neurons in the lab opens the door for a wide range of research into these important cell types. Scientists could learn more about their role in neurodevelopmental disease and the brain as a whole.

"When thinking about assembling brain models, missing this cell type is actually quite critical," Mostajo-Radji said. "Now, we can make a more realistic model of the brain."

Changing identity

Next, to further challenge the idea that these cells have a fixed identity, the researchers investigated how the external environment around subtypes of neurons can affect the cell's identity.

To do so, they took another kind of inhibitory neuron, called somatostatin neurons, and added them to the 3D organoid model. They observed that in these conditions, some somatostatin neurons transitioned into parvalbumin-positive neurons.

While they are not sure about the exact genetic and environmental conditions that enabled the transition, just knowing that this change can occur in living cells in the lab opens up the possibility that the processes could be happening in the brain as well.

"It's possible that this process of changing identity might actually happen naturally in the brain," Mostajo-Radji said. "We don't know that yet, but maybe there is a process in which this has actually been observed in the brain, but overlooked. It's an exciting window we should explore, and some other labs around the country are starting to think the same way."

While they have some initial ideas about which genetic pathways might be at play, the researchers want to further explore what factors are responsible for enabling this fluidity of neuronal identity. The researchers also want to further investigate the excitatory cells to find out how they influence the fate of the inhibitory cells.

More information: Mohammed A. Mostajo-Radji et al, Fate plasticity of interneuron specification, *iScience* (2025). DOI: 10.1016/j.isci.2025.112295

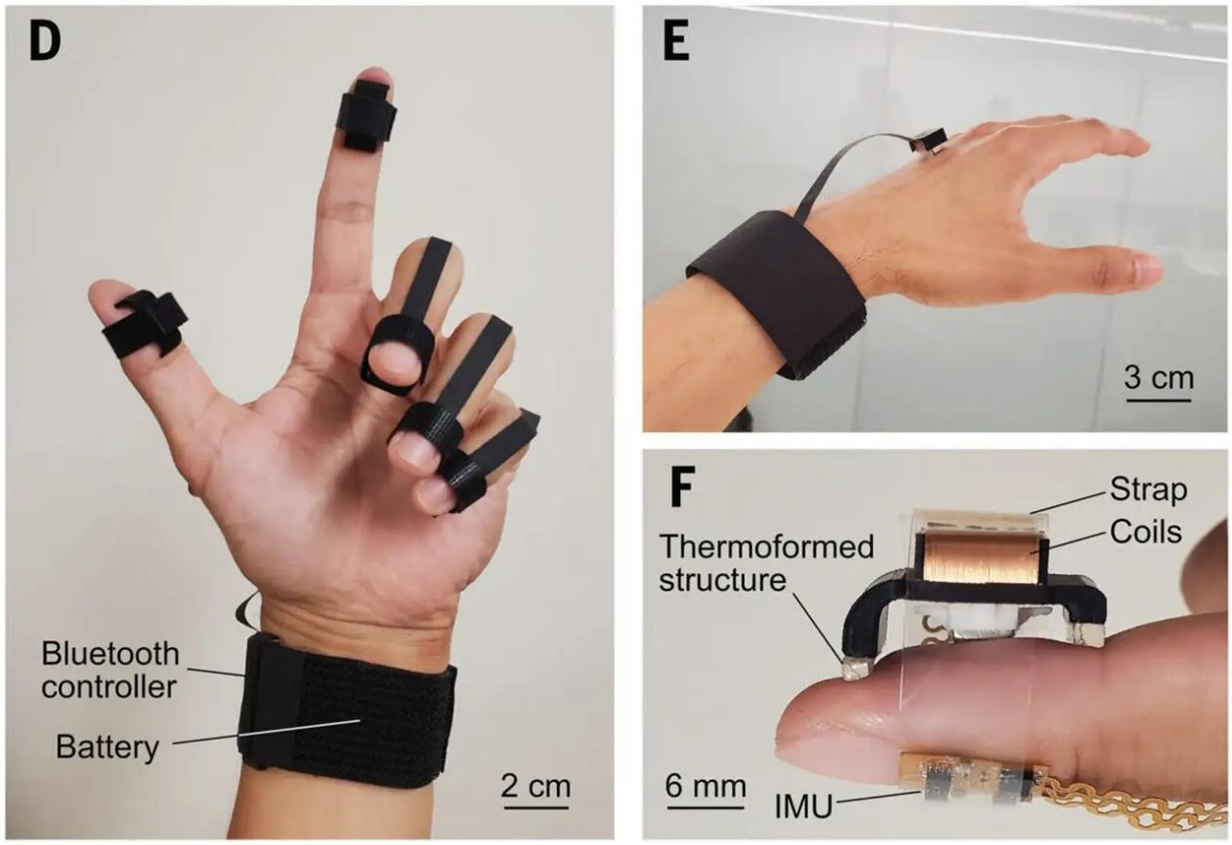
Provided by University of California - Santa Cruz

Cutting-edge wearable device mimics the complexity of human touch

Cutting-edge wearable device mimics human touch

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.

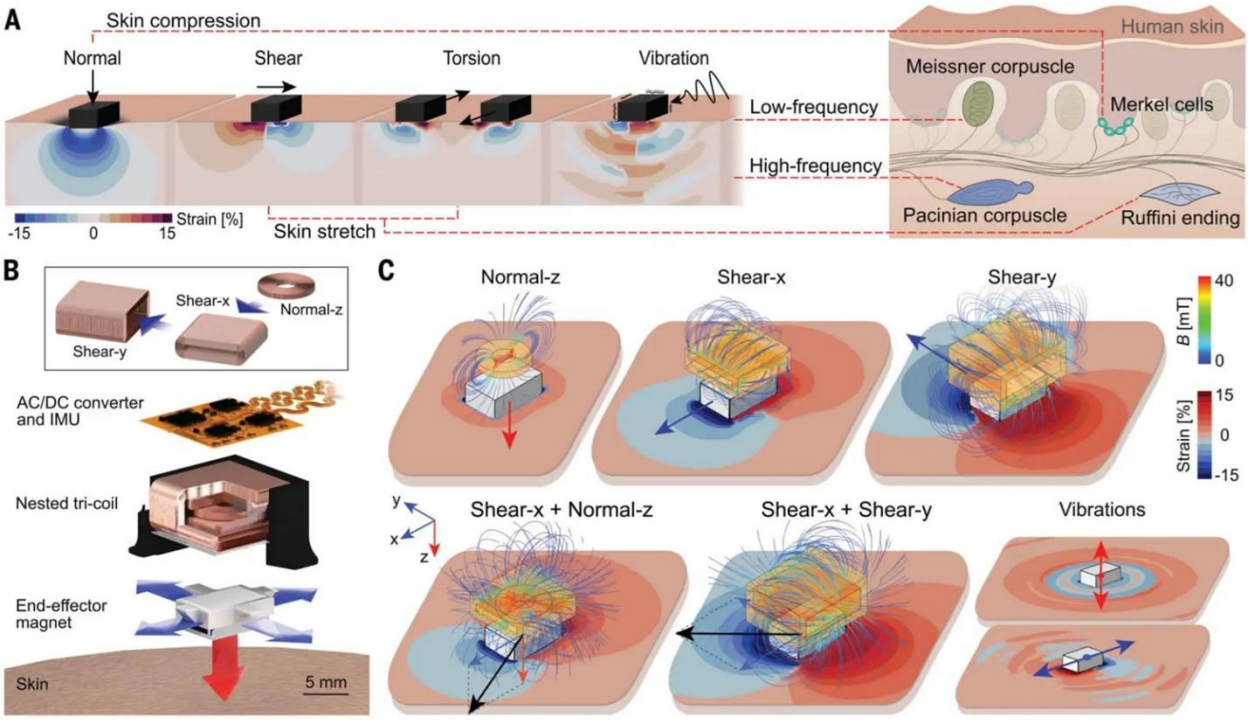


The new actuator, developed by engineers at a top research university, brings something never before seen in haptic devices: full freedom of motion. That means it can move and apply force in all directions — up, down, side to side, and even in circles.

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

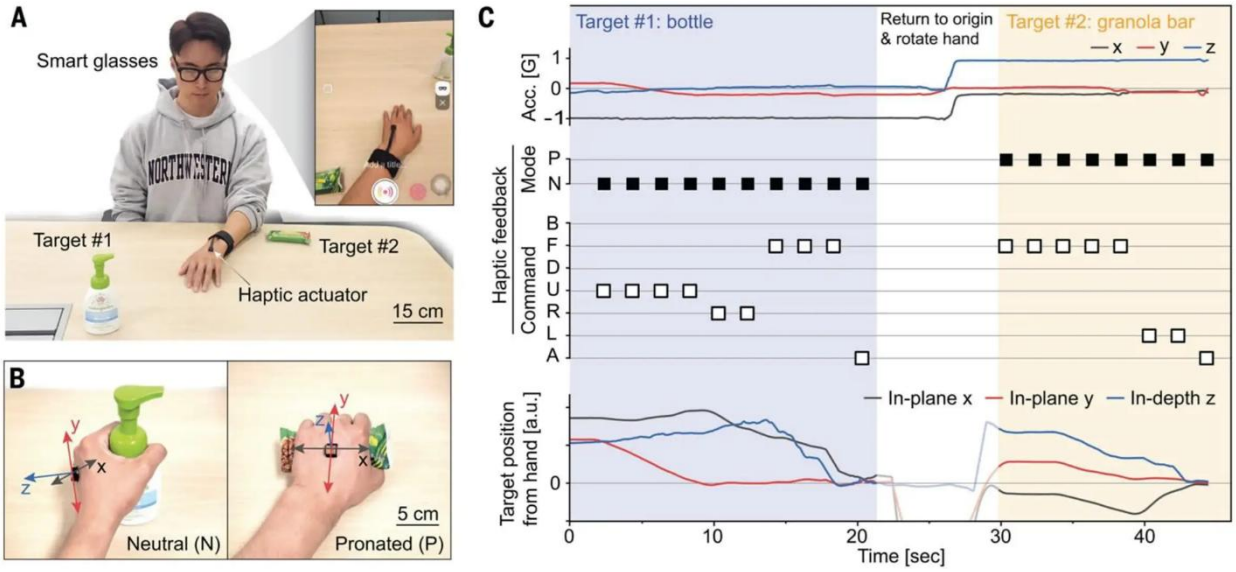
©Science

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

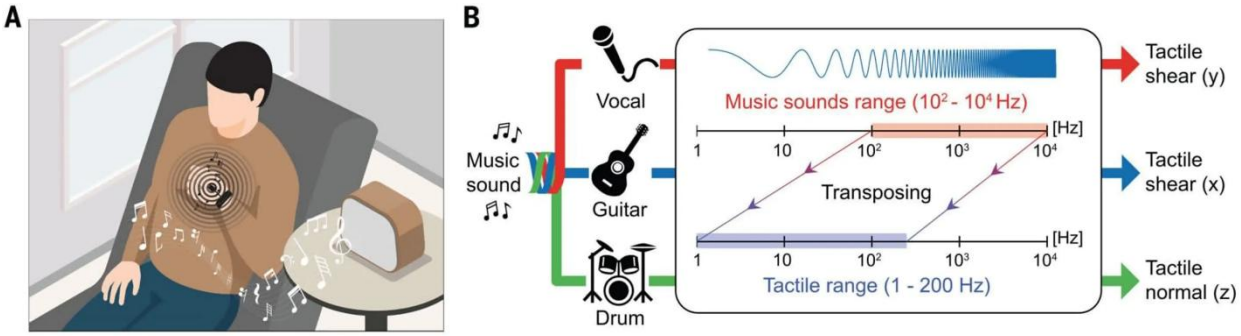
©Science

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

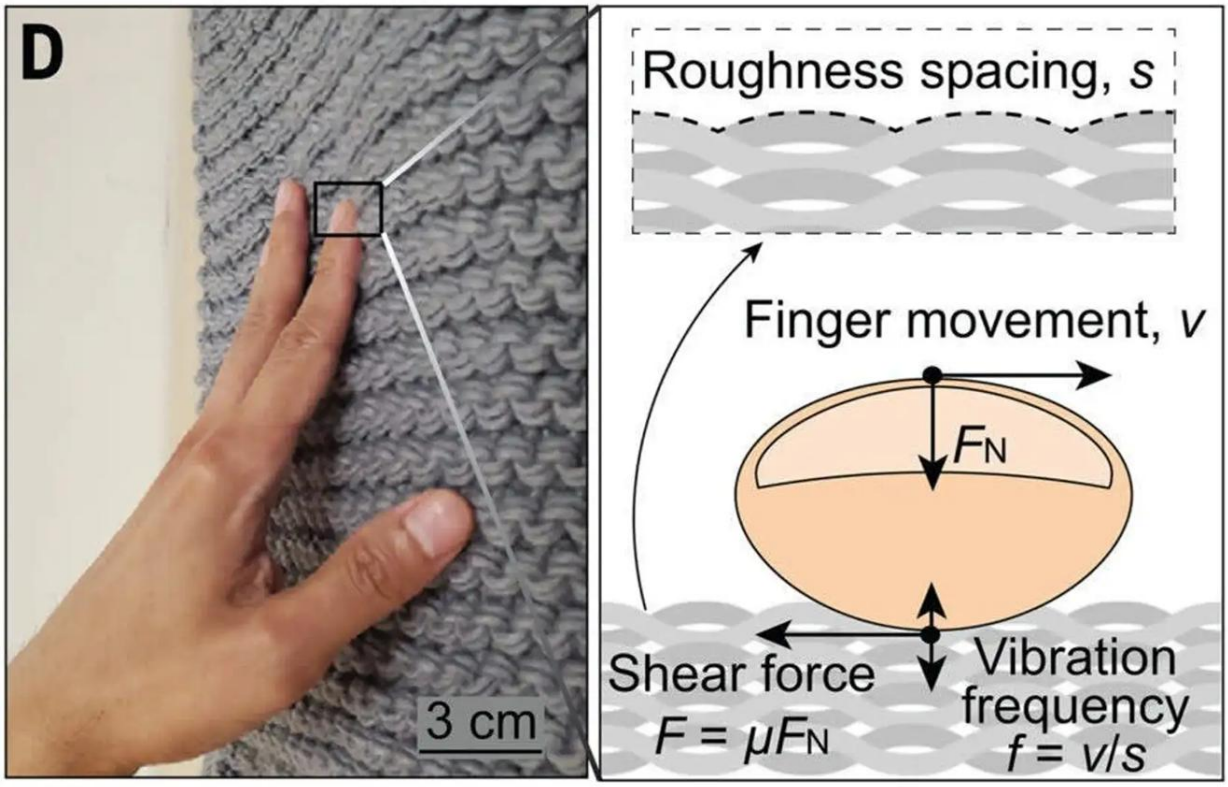
©Science

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.

The brain may 'move' between related ideas in the same way it navigates from one location to another

The brain might use the same processes to connect related concepts as it does to navigate a physical space, according to a new study.© kontekbrothers via Getty Images

To learn our way around a new city, we often use maps and landmarks to find the quickest and most reliable route between two places. Now, new research shows that our brains might use similar processes to "navigate" between related concepts.

Researchers have developed a mathematical model to examine how the brain represents both spatial and semantic information. The latter includes knowledge about the meaning and significance of different people, places and things; brain activity related to these concepts crops up when a person sees a person, place or thing in real time and when they recall it in a memory.

The model showed how both spatial and semantic information could be represented in the same regions of the brain — and this suggests that the brain can handle both types of information in similar ways, the scientists reported March 10 in the journal PNAS.

Two parts of the brain that focus on memory and navigation — the hippocampus and the entorhinal cortex — both contain neurons that fire when people move through their physical surroundings. They also contain

neurons that fire in response to certain concepts or ideas, known as concept cells. This led researchers to suspect these thought processes might be related.

"Spatial representations and conceptual representations, and also semantic computing and spatial computing, seem very different," study co-author Tatsuya Haga, a computational neuroscientist at the National Institute of Information and Communications Technology in Japan, told Live Science. Semantic and spatial computing refers to how brains and computers process information in these separate realms.

"However, there's a connection between those two different things," Haga said. "So maybe the brain, especially the hippocampus and entorhinal cortex, is using one principle to compute many things, including language."

Haga and his colleagues developed a mathematical model that mimics certain functions in the hippocampus to show how these ways of thinking are related. The model combines two functions that help control how the processing hub shifts from one place or idea to another: a successor representation, which predicts the probability of moving from one physical space to another, and word embedding, which captures the relationships between words.

The team then asked their model to navigate a simulated physical or conceptual space. The "physical" space was a simulated structure, sometimes with separate rooms, while the conceptual space involved traversing the metaphorical "distance" between related words using analogies.

In response to these tasks, the model produced patterns that resemble the activity of two kinds of neurons in the hippocampus and entorhinal cortex: one involved in spatial awareness and another involved in concept recognition.

The team showed that the same algorithm that can be used to navigate virtual spaces can also capture relationships between related concepts, such as countries and their capitals. In this example, to navigate from the concept of "France" to that of "Berlin," the model could first activate a concept cell for capital cities, which would lead it from "France" to "Paris," and then activate an additional cell representing "Germany," which would lead it to "Berlin."

"When you're trying to navigate a maze city, you have to have some kind of map with landmarks and directions," Rob Mok, a computational neuroscientist at

Royal Holloway, University of London who was not involved in the study, told Live Science. "And the idea is that you can do that when you're thinking as well."

The model can use various analogies to overcome the metaphorical distance between different semantic concepts.

"So if I'm thinking about a dog, how do I get to 'cat'? Or how do I get to 'king'?" Mok said. "These are different directions, and you might need to navigate in different ways to get there."

The new mathematical model shows one possible way the human brain might process both spatial and semantic information. However, no one has shown whether actual brains learn and process information in the exact same way the model does.

Haga told Live Science that he hopes to investigate this biological mechanism in future work using models that are more similar to biological brains.

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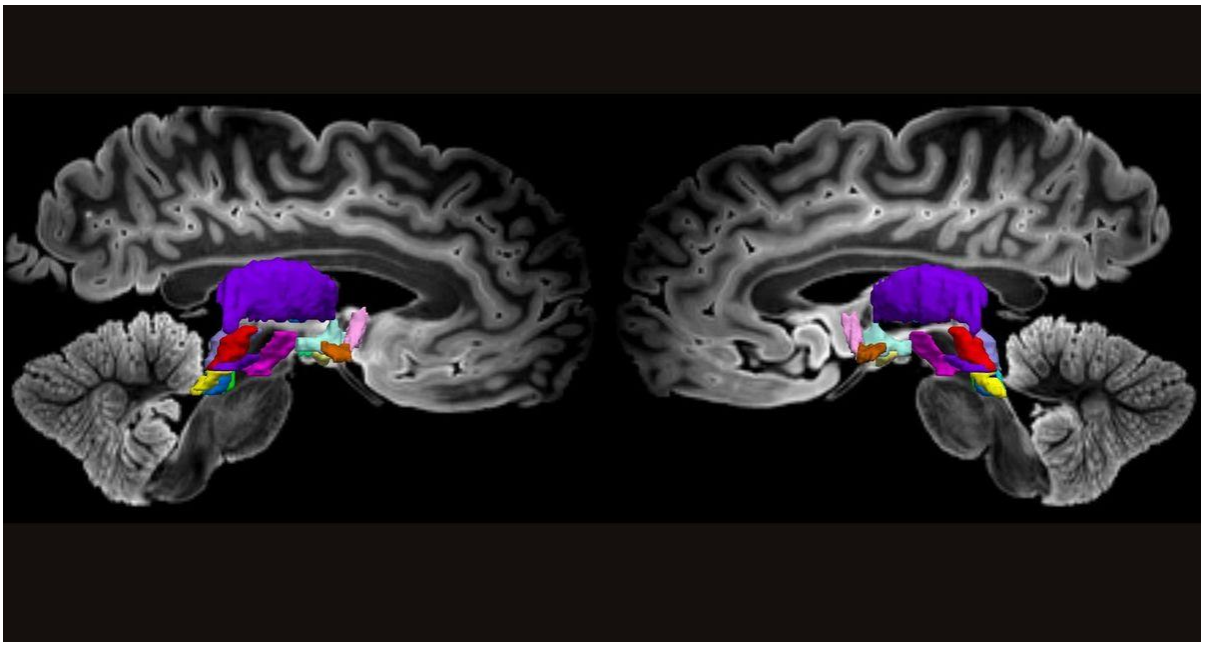
Super-detailed map of brain cells that keep us awake could improve our understanding of consciousness

published May 1, 2024

A new map of a brain network that sustains wakefulness in humans could help improve our understanding of consciousness.



The major nodes of a human brain network that keeps us awake are shown color-coded in this MRI scan of a postmortem brain. (Image credit: Edlow et al., Sci. Trans. Med., 16 eadj4303 (2024). (Cropped by Live Science.))

Scientists have charted a comprehensive map of the brain cells responsible for keeping us awake. In doing so, they aim to better understand the mechanisms that enable human consciousness and to improve treatments for people in comas and vegetative states.

"It's a beautiful study," said Dr. Nicholas Schiff, a professor of neurology and neuroscience at Weill Cornell Medicine who was not involved in the new research. "It's a map of everything."

Schiff, who has collaborated with some of the study's authors in the past, hopes the new map can serve as a template for scientists to go back and look at patients with altered states of consciousness. Such work could help clarify exactly how this wakefulness network can be disrupted and what's required to get it back online. It's a tool that could help

scientists pinpoint which brain activity is "necessary and sufficient" to keep someone awake and aware, Schiff told Live Science.

Mapping consciousness

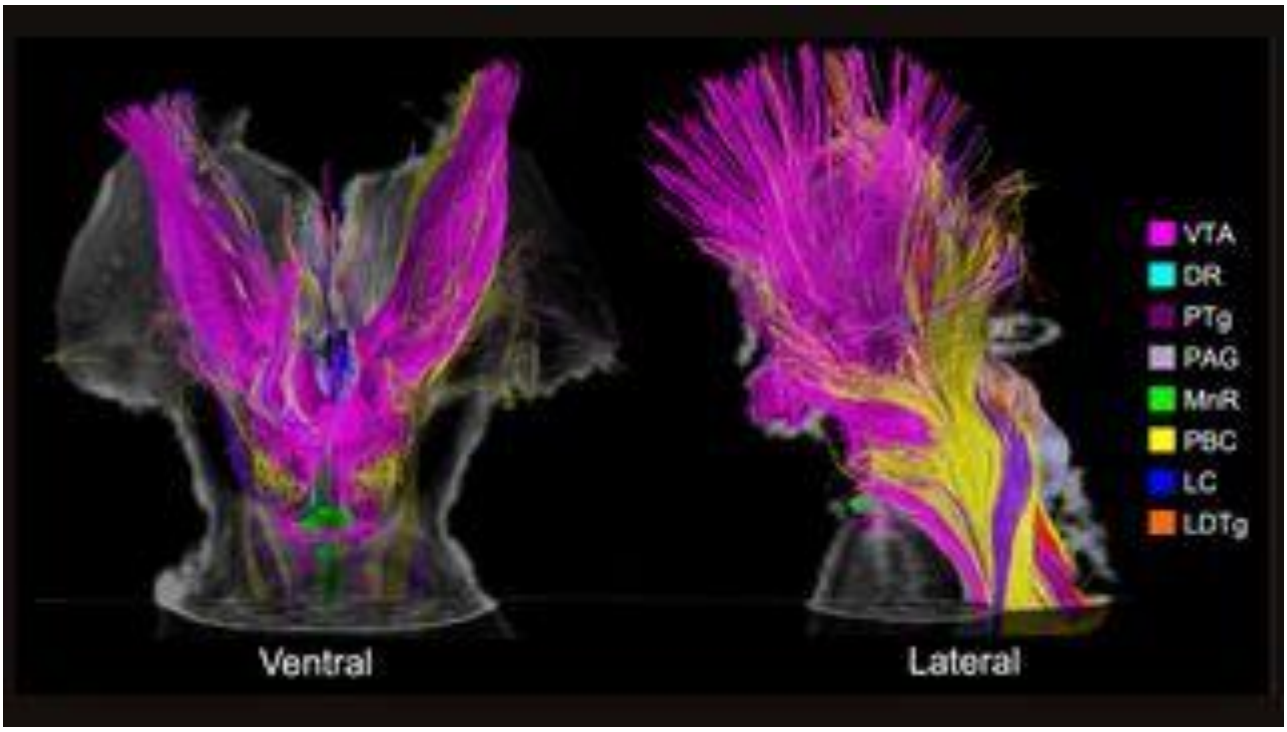
Human consciousness arises from a delicate dance between the wrinkled surface of the brain, known as the cerebral cortex, and deeper "subcortical" structures beneath it. Circuits in the cortex direct our attention and process information from the world around us, while the subcortical networks plug into these circuits from below, essentially keeping them active.

"It sends the signals that activate and stimulate the entire rest of the brain," said first author Dr. Brian Edlow, co-director of Mass General Neuroscience and director of the Laboratory for NeuroImaging of Coma and Consciousness.
Thus, consciousness is a "seamless interaction of these subcortical networks with these cortical networks," Schiff said. "It's an artifice, I think, to try to separate these things."

But scientists' understanding of humans' subcortical networks is incomplete. It relies heavily on animal experiments, in which scientists can inject trackable chemicals into the brain and then remove the organ to get a good look at where they ended up. In living humans, these deep-seated networks are located near major arteries and air-filled sinuses, and they also move a bit with each breath, making standard brain scans less crisp and hard to decipher. By contrast, networks in the human cortex are easier to image and have been much better studied.

To help close this knowledge gap, the scientists behind the new study looked at brains from three middle-age organ donors. Using postmortem brains allowed the team to "map brain networks at ultrahigh resolution and to see connections that simply cannot be seen when you're scanning a living human being," Edlow told Live Science.

These organ donors had no neurological problems when they died, and their brains were carefully preserved in formaldehyde. The researchers stained the brains with colorful chemicals to mark different types of brain cells and then put the brains in an magnetic resonance imaging (MRI) scanner for up to 48 hours.



These scans of postmortem brain tissue show many of the tracts in the network that sustains wakefulness in humans. (Image credit: Edlow et al., Sci. Trans. Med., 16 eadj4303 (2024). (Cropped by Live Science.))

This resulted in incredibly high-resolution maps of subcortical structures that had been tied to wakefulness in previous research. The team manually traced connections between the brain cells in these structures, taking into account the direction water would flow down their wires. This metric captured by MRI can help reveal how strongly different nodes in a network are linked.

This work revealed major nodes of the wakefulness network in several subcortical structures — the brainstem, hypothalamus and thalamus — as well as part of the cortex called the basal forebrain. This network was confirmed to be linked to a circuit involved in awareness. Known as the default mode network, it is very active when we're daydreaming and not focused on a particular task.

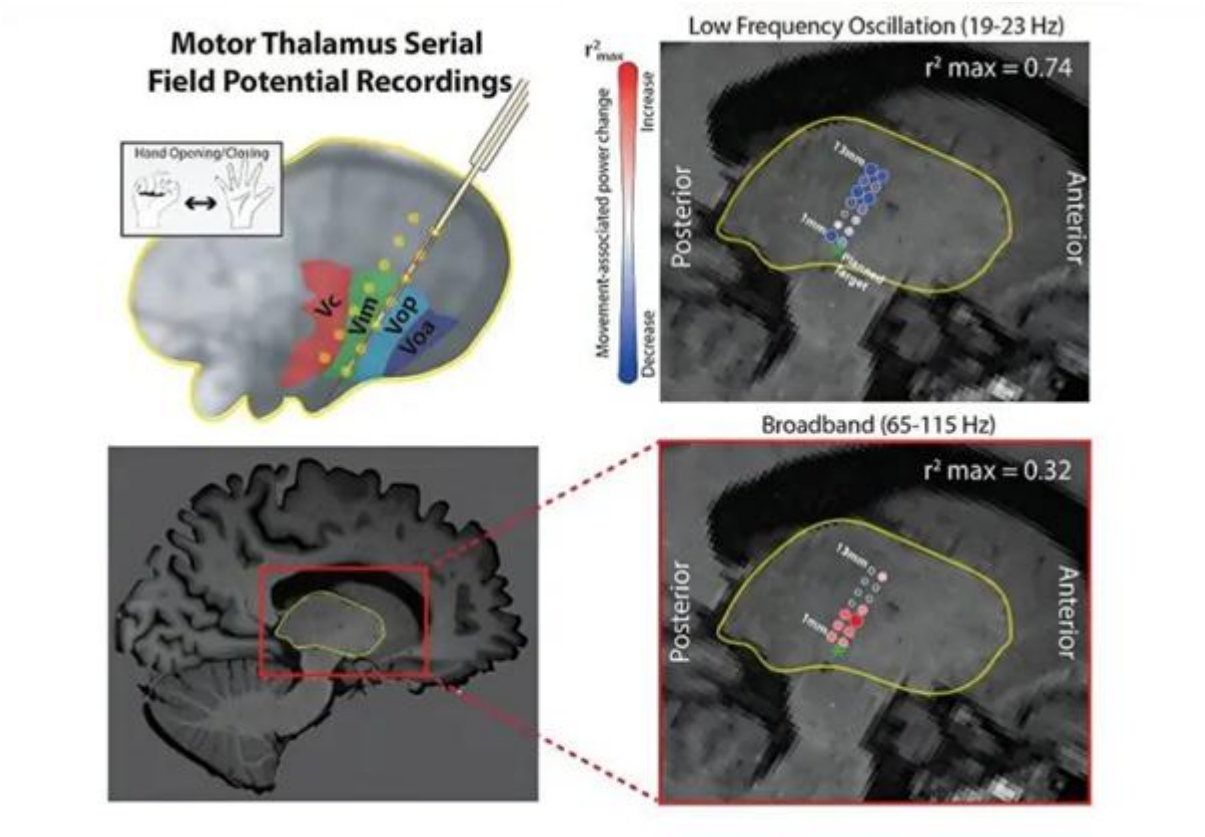
To back up their work in postmortem brains, the team also looked at functional MRI data from more than 80 people who'd participated in the Human Connectome Project, a government-led effort to map all the networks in the human brain. These additional brain scans, which looked at the flow of oxygenated blood, pointed out a hub where these awareness and wakefulness networks meet: the ventral tegmental area.

Taken together, the postmortem brain scans provided maps of highways in the brain, while the live scans showed traffic patterns along those roads. "We view our findings as an initial map that is beyond the spatial resolution that has been achieved previously," Edlow said. Looking to the future, the researchers hope to improve upon the map's resolution even more.

At this point, it's unclear exactly how the new map could shape the treatment of patients in comas, vegetative or minimally conscious states, Schiff noted. But it should be a useful tool to better understand and treat these conditions, he added.

"We envision that these connectivity maps will allow us to piece together, one individual at a time, the combination of connections that are necessary and sufficient to recover consciousness," Edlow said.

Thinking outside the box: Uncovering a novel approach to brainwave monitoring with 'broadband'

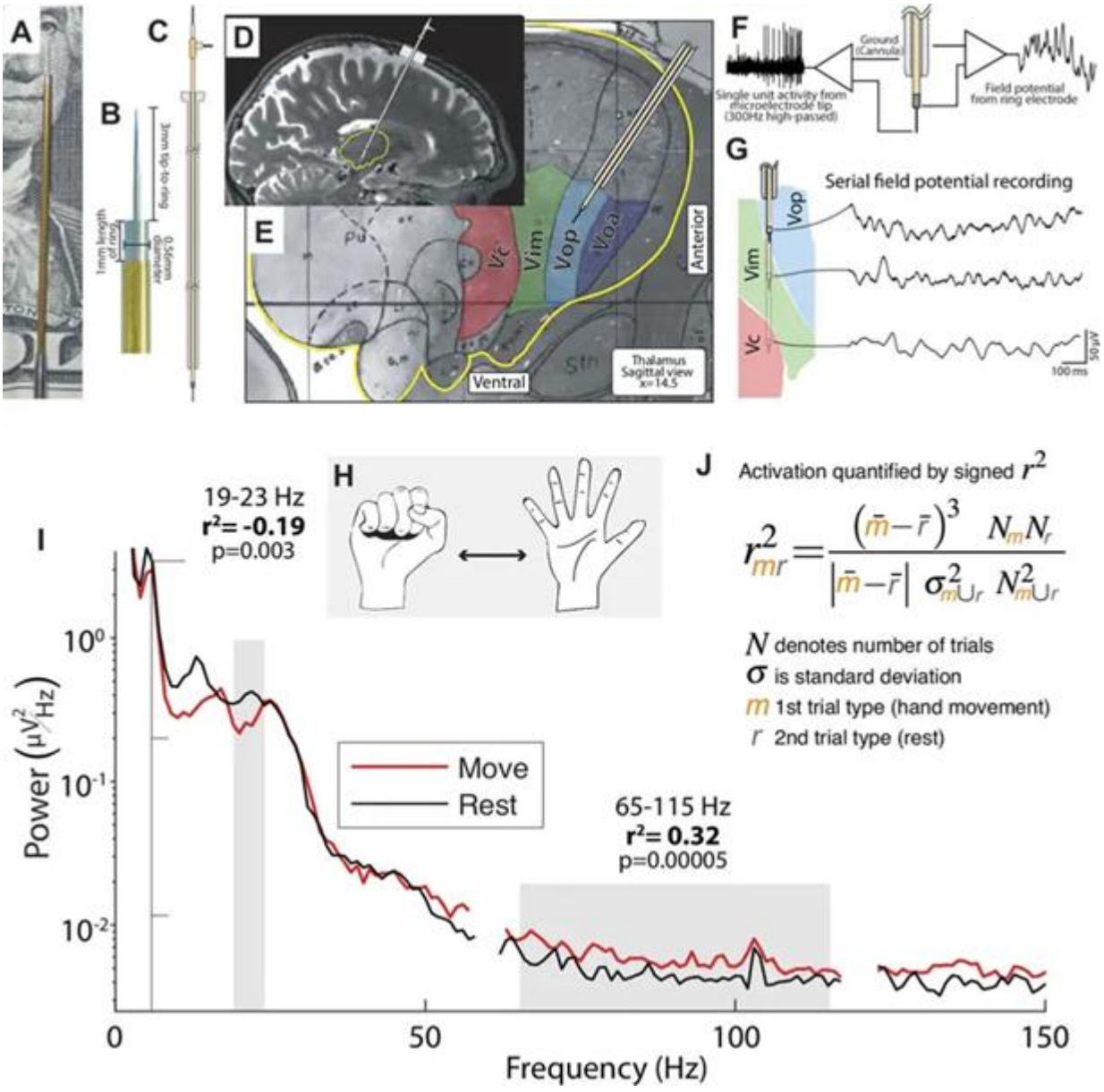


Abstract. Credit: Journal of Neurophysiology (2024). DOI: 10.1152/jn.00419.2024

Mayo Clinic researchers have found a new way to more precisely detect and monitor brain cell activity during deep brain stimulation, a common treatment for movement disorders such as Parkinson's disease and tremor. This precision may

help doctors adjust electrode placement and stimulation in real time, providing better, more personalized care for patients receiving the surgical procedure. The study is published in the *Journal of Neurophysiology*.

Deep brain stimulation (DBS) involves implanting electrodes in the brain that emit electrical pulses to alleviate symptoms. The electrodes remain inside the brain connected to a battery implanted near the collarbone and controlled by a remote control. While a neurologist and neurosurgeon monitor the brain waves throughout the surgery, the monitoring typically is limited to a narrow frequency range that provides a rough snapshot of brain activity.



Experimental and signal-processing methods. Credit: Journal of Neurophysiology (2024). DOI: 10.1152/jn.00419.2024

However, Mayo Clinic researchers used more sensitive, research-grade equipment and custom algorithms to record a broader frequency range of brain cell activity that yielded higher resolution and more precise information on when and where brain cells were firing in patients during DBS surgery.

"We looked at brain activity in a different way and recorded a type of brain signal called 'broadband' that reflects the combined activity across all frequencies and is related to the firing of all brain cells in that region. We found that the broadband activity signal increased with movement and was more precise in location than the standard, more narrow frequency signal," says lead author Bryan Klassen, M.D., a neurologist.

Dr. Klassen and colleagues detected the broadband signal in the motor thalamus, a region deep within the brain that controls movement. Previous studies have detected it only on the surface of the brain.

The researchers recorded broadband signals associated with hand movement in 15 patients undergoing awake DBS. Each of the patients were instructed to open and close their hands while the researchers recorded brain cell activity in their thalamus.

"This study enhances our understanding of how the thalamus, a brain region that is frequently targeted for deep brain stimulation, processes movement. It may lead to more precise mapping of the brain as well," says study co-author Matthew Baker, Ph.D., a postdoctoral neurosurgery fellow at Mayo Clinic.

Using broadband to monitor during DBS surgery may improve the treatment and outcomes for patients.

"These findings underscore the remarkable advances we can achieve through the close collaboration between the neurology and neurosurgery departments and will help us develop the next generation of brain stimulation therapies," says neurosurgeon Kai Miller, M.D., Ph.D., the study's senior author.

The next steps for this research involve further exploring how these brain activity patterns in the thalamus can be used to improve neurostimulation therapy, says Dr. Baker, a recent graduate of Mayo Clinic Graduate School of Biomedical Sciences.

"We will be investigating how this signal responds to different types of movements and whether we can use it to control new devices that only stimulate when patients need it, as opposed to constant stimulation, which is more prone to cause side effects," he says.

More information: Bryan T. Klassen et al, Spectral changes in motor thalamus field potentials during movement, *Journal of Neurophysiology* (2024). DOI: 10.1152/jn.00419.2024

Provided by Mayo Clinic

Mapping the mind: New framework links brainwaves to individual cognitive states

The complexity of the human brain—86 billion neurons strong with more than 100 trillion connections—enables abstract thinking, language acquisition, advanced reasoning and problem-solving, and the capacity for creativity and social interaction. Understanding how differences in brain signaling and dynamics

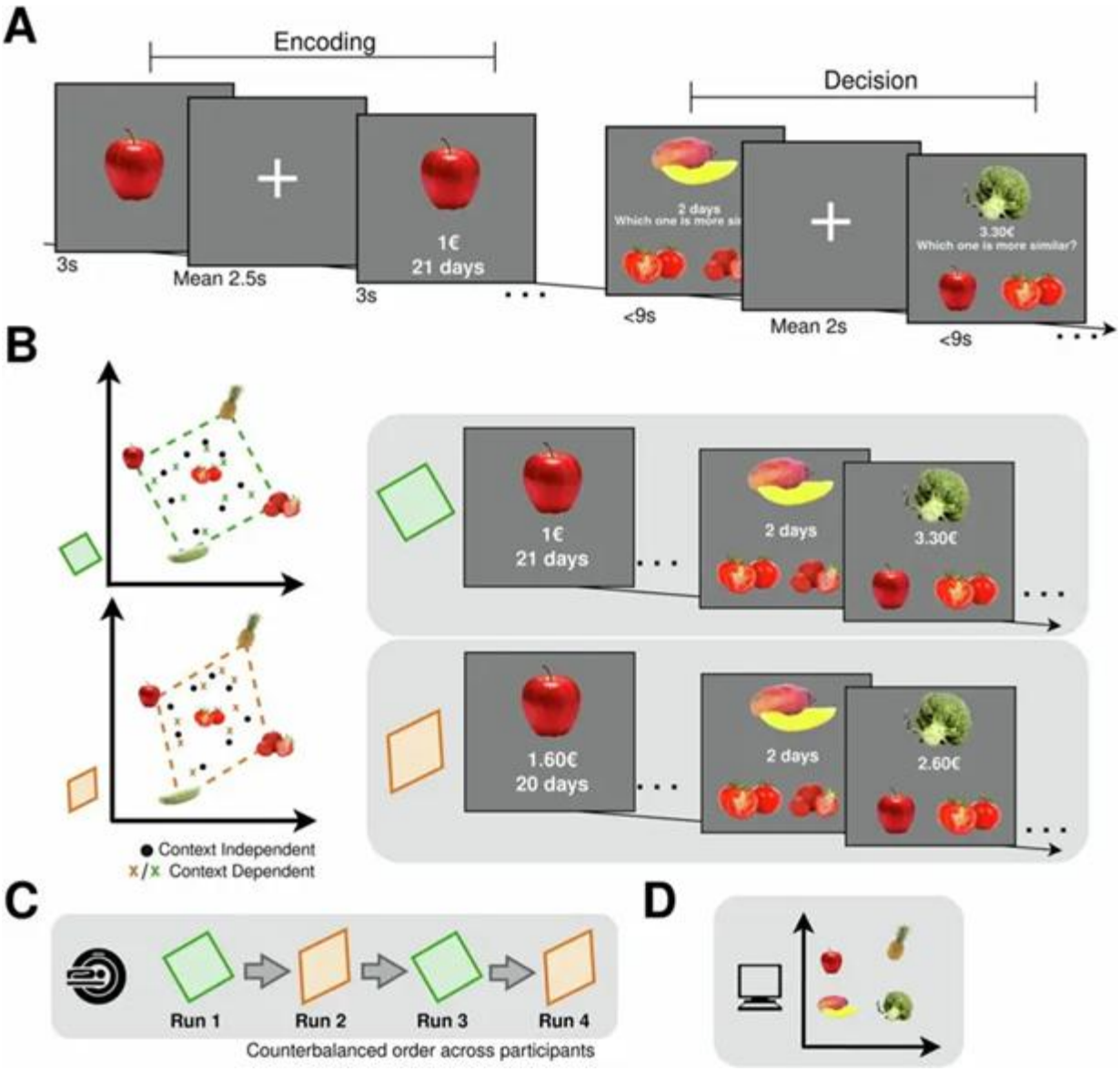
produce unique cognition and behavior in individuals has long been a goal of neuroscience research, yet many phenomena remain unexplained.

A study from neuroscientists and engineers at Washington University in St. Louis addresses this knowledge gap with a new method to create personalized brain models, which offer insights into individual neural dynamics. Led by ShiNung Ching, associate professor in the Preston M. Green Department of Electrical & Systems Engineering in the McKelvey School of Engineering, and Todd Braver, professor in the Department of Psychological & Brain Sciences in Arts & Sciences, the work, published Jan. 17 in *PNAS*, introduces a novel framework that will allow the researchers to create individualized brain models based on detailed data from noninvasive, high-temporal resolution brain scans. Such personalized models have applications in research and clinical settings, where they could support advances in neuroscience and treatment of neurological conditions.

"This research is motivated by our need to understand person-to-person variation in brain dynamics," said first author Matthew Singh, who conducted the research while a postdoctoral fellow with Braver and Ching at WashU and is now an assistant professor at the University of Illinois Urbana-Champaign. "We're not explaining the full range of biophysical mechanisms at work in the human brain, but we are able to shed light on why healthy individuals have different brain dynamics with our new modeling framework, which gives us insights into brain mechanics and testable predictions of brain phenomena."

A key advantage of the team's technique is its ability to see individual variations in the generation of alpha and beta waves and link them to global changes in the brain. These two types of brainwaves, characterized by their different electrical frequencies, are associated with different cognitive states and functions. For example, alpha waves are associated with relaxed states, such as meditation, while beta waves are linked to alert and active states, such as decision-making and problem-solving. Variation in the peak frequency of alpha waves has traditionally been a reliable measure of individual differences in the brain and behavior.

How the brain uses context boundaries to guide decision-making in both spatial and abstract environments

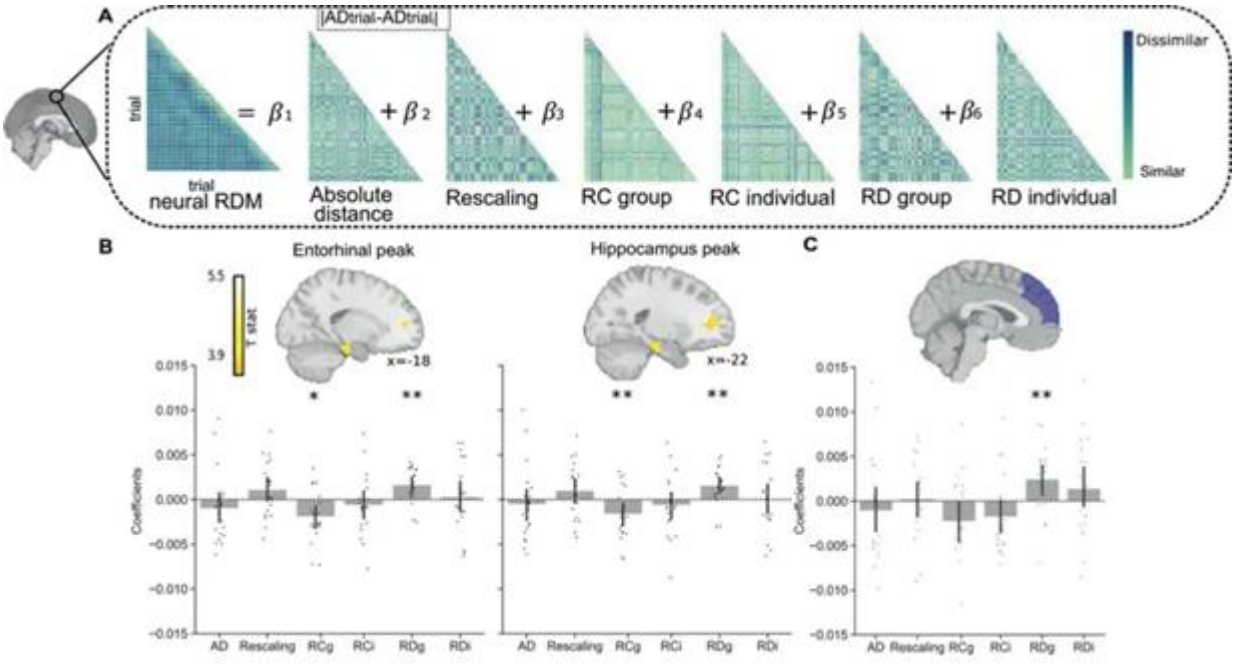


Experimental paradigm. Nature Communications (2025). DOI: 10.1038/s41467-025-57644-6

The DAM-Decision and Memory group at Universitat Jaume I in Castelló, led by Raphael Kaplan and composed of researchers from Spain, Italy and the United States, has recently published the results of two studies that provide new insights

into human brain behavior in everyday activities such as decision-making and social interaction.

In a new line of research by Dr. Kaplan, doctoral students Mariachiara Esposito and Lubna Abdul have shown that the hippocampal and medial prefrontal cortex regions of the brain use the boundaries of a context to guide decision-making in both spatial and abstract contexts, as explained in the article "Flexible hippocampal representation of abstract boundaries supports memory-guided choice" recently published in the journal *Nature Communications*.



Egocentric anchoring-and-adjustment in the hippocampal formation. Credit: PLOS Biology (2025). DOI: 10.1371/journal.pbio.3003050

The boundaries of an environment help us to navigate in physical space and remember where we have been. The hippocampus is responsible for remembering these positions and is sensitive to changes in these spatial boundaries.

What was not clear is whether hypothetical limits, for example, the relationship between the size and the price of a flat when you are looking for one for a person or for a family, involve the same regions of the brain in the same way. This research demonstrates that the brain can integrate the limits of different characteristics and adapt them to changes in context and criteria in order to guide everyday decisions such as economic decisions.

Social anchoring

In another of Dr. Kaplan's lines of research, doctoral student Marta Rodríguez has shown that subjective preferences affect the way we link different people together. For example, when we organize a meeting and need to remember our guests' preferences and the relationship between them. The brain regions responsible for remembering other people's preferences also show us how they differ from our own, even if a comparison between them is not necessary.

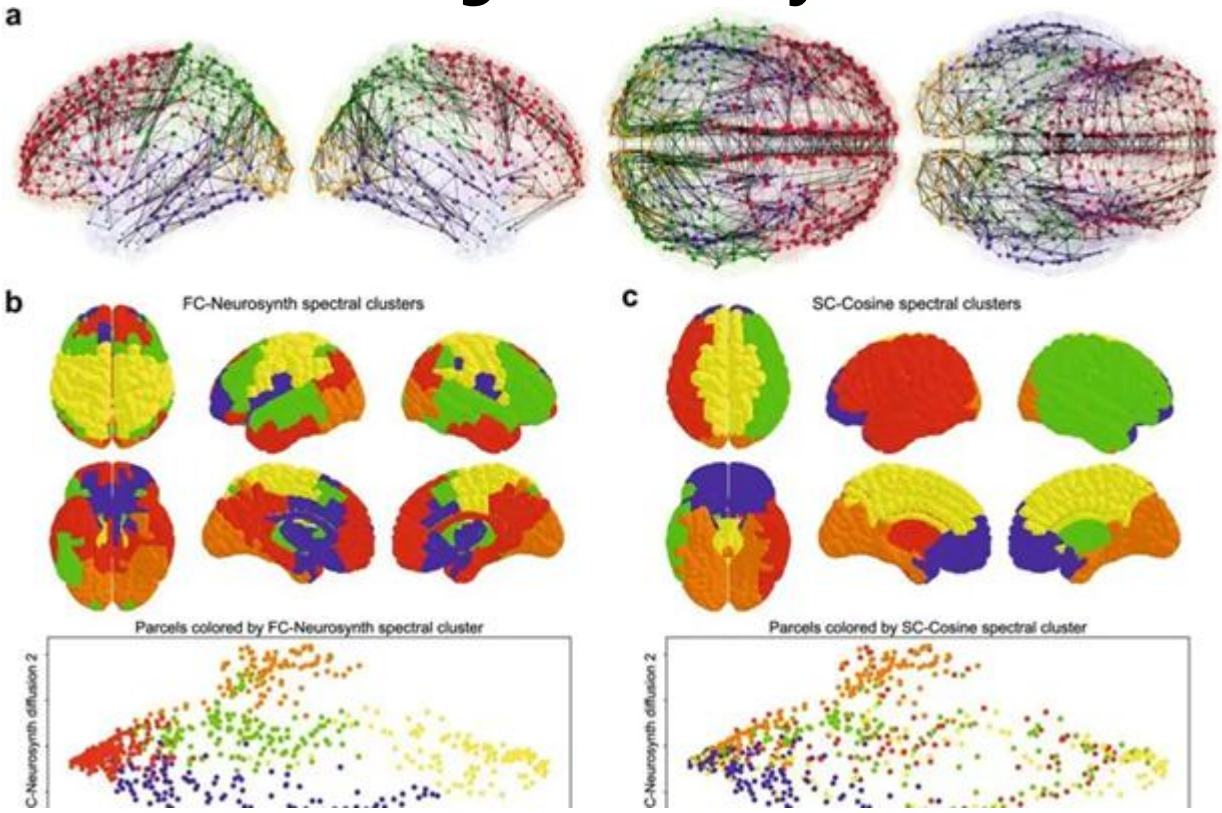
This phenomenon, known as "social anchoring," suggests that our personal biases influence how we remember other people's preferences. The results of the study "Social knowledge about others is anchored to self-knowledge in the hippocampal formation," also recently published in the journal *PLOS Biology*, provide key information on how our cognitive biases shape social memory.

More information: Mariachiara Esposito et al, Flexible hippocampal representation of abstract boundaries supports memory-guided choice, *Nature Communications* (2025). DOI: 10.1038/s41467-025-57644-6

Marta Rodríguez Aramendía et al, Social knowledge about others is anchored to self-knowledge in the hippocampal formation, *PLOS Biology* (2025). DOI: 10.1371/journal.pbio.3003050

Provided by Universitat Jaume I

Neuronal wiring's role in brain function varies across regions, study finds



Global comparison between structural and functional connectivities. Credit: Nature Communications (2024). DOI: 10.1038/s41467-024-51395-6

Different brain regions are connected by—and interact through—networks of neurons. But the extent to which neuronal wiring drives shared function between these different regions is not well understood. Is this structure-function relationship the same throughout the brain? The same across functions?

Yale researchers have now found that this relationship is variable, which they reported recently in *Nature Communications*.

For the study, the researchers pulled both structural and functional brain data from large data repositories and calculated how well the coactivation of different brain regions (function) could be explained by the neurons that directly connected them (structure). They evaluated this across brain regions and more than 300 brain functions.

"We found that this relationship exists on a gradient," said lead author Evan Collins, who is now a graduate student at MIT but who conducted the research as an undergraduate in the Yale Neuroscience Neuroanalytics research group directed by Dennis Spencer and Hitten Zaveri.

"The relationship between structure and function was stronger in the primary sensory and motor cortical areas and for perceptual and motor functions," Collins said. "It was weakest in the association cortex for complex cognitive functions. Moreover, the way in which humans discern meaning from words mirrors this neural gradient, revealing how our language informs us about our brain organization."

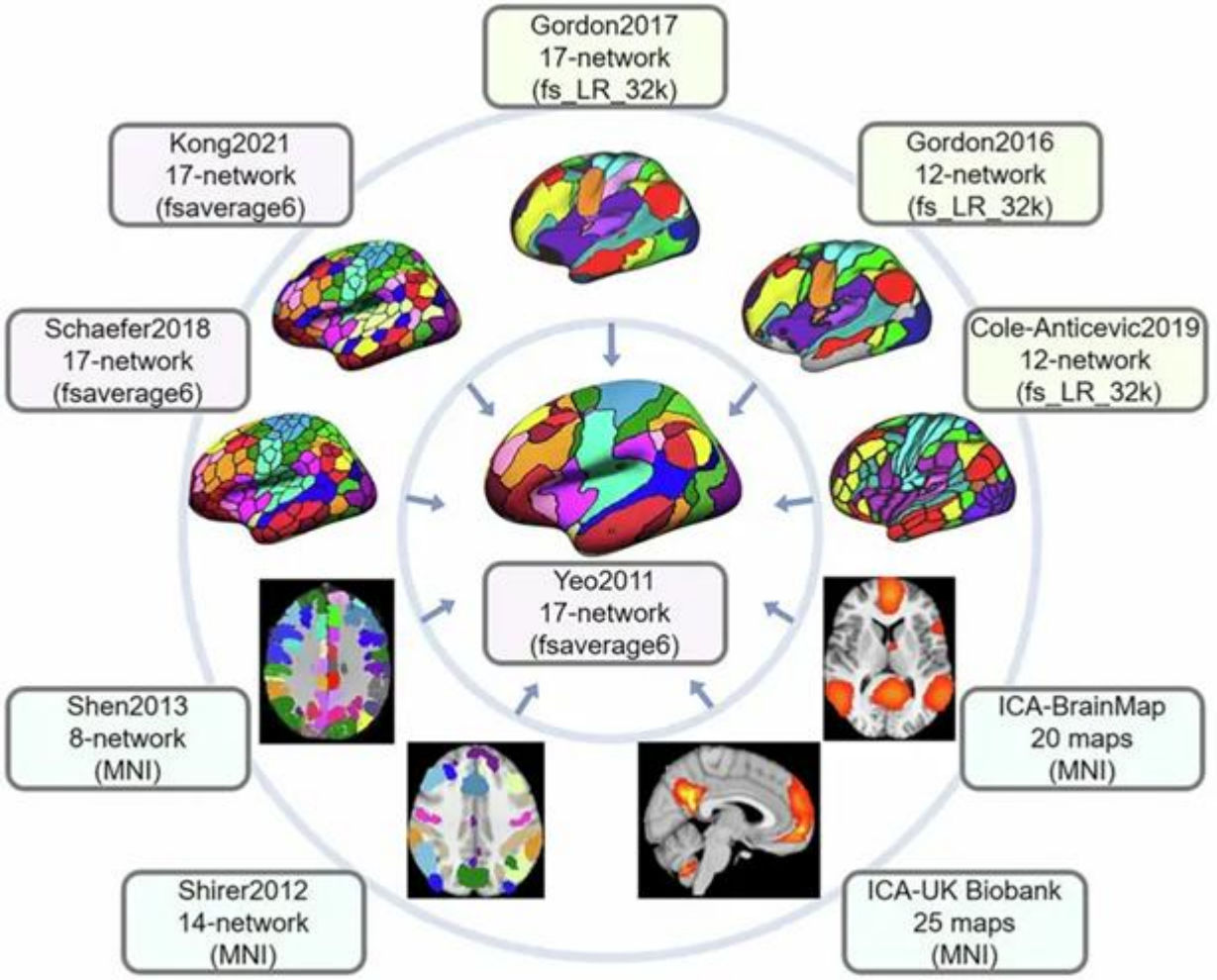
The evolution of the human brain may help explain this gradient. One possible reason is that while direct connections between brain regions were sufficient for such faculties as vision and movement, as the brain developed more advanced capabilities, like complex cognition, these direct connections had maxed out their usefulness.

"It's possible that the brain developed more indirect connections between regions in order to establish new, more advanced abilities," said Zaveri, co-senior author of the study and associate professor of neurology at Yale School of Medicine.

More information: Evan Collins et al, Mapping the structure-function relationship along macroscale gradients in the human brain, *Nature Communications* (2024). DOI: 10.1038/s41467-024-51395-6

Provided by Yale University

Neuroscientists unveil digital 'translator' for brain studies



Example atlases included in the Network Correspondence Toolbox (NCT). Credit: Nature Communications (2025). DOI: 10.1038/s41467-025-58176-9

UCLA Health researchers have helped to develop a new digital toolbox to create a "common language" for brain network studies, potentially accelerating new discoveries and treatments for neurological and psychiatric conditions.

In a study recently published in the journal *Nature Communications*, the authors say the open-source software will help researchers worldwide overcome a longstanding hurdle in brain imaging research.

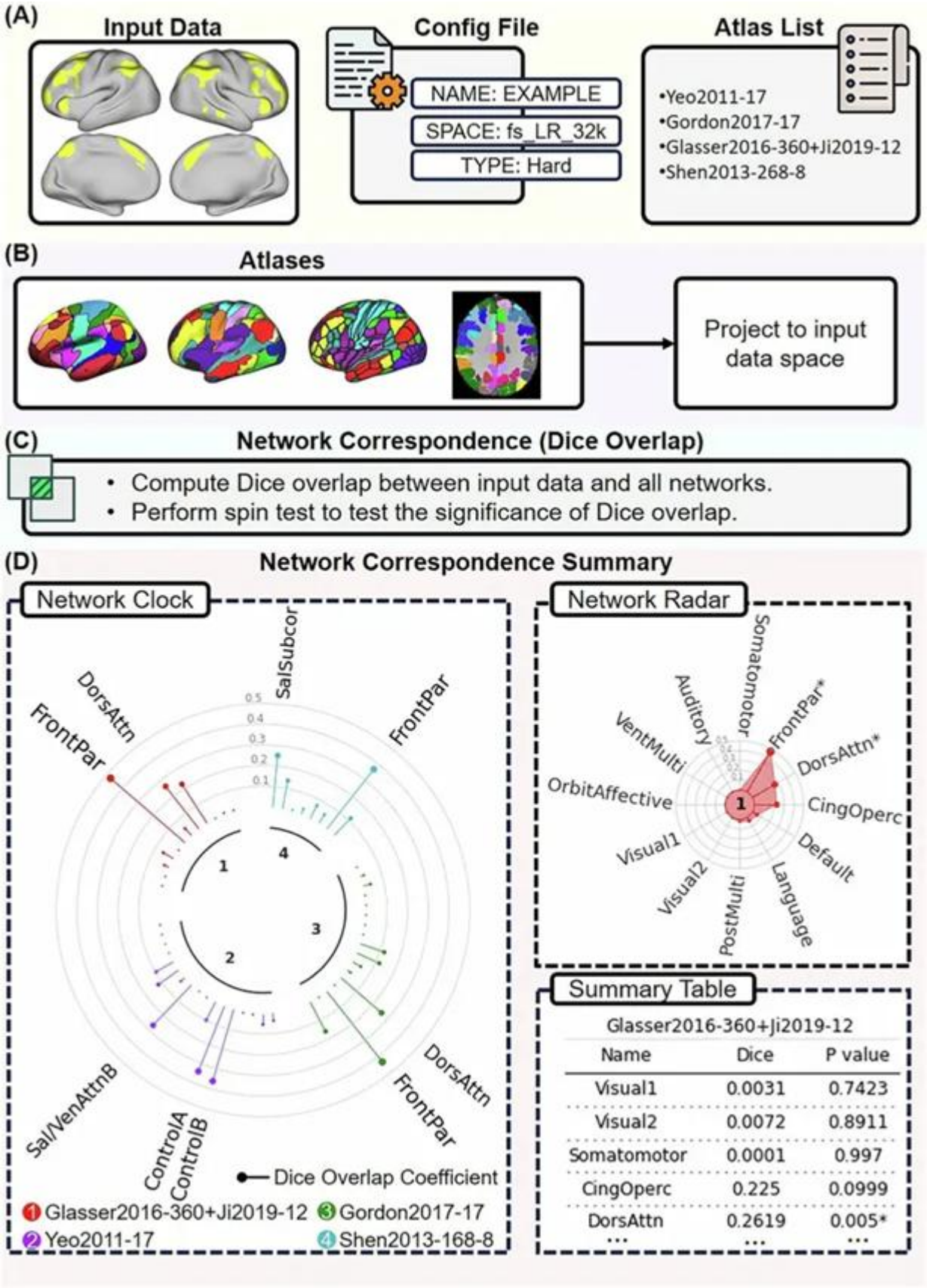
"As long as people have been interested in studying the brain, they have tried to map it out by answering a basic question: how many brain regions are there?"

said study senior author Lucina Uddin, a UCLA Health Psychiatry and Biobehavioral Sciences Professor and Director of the UCLA Brain Connectivity and Cognition Laboratory.

"You can divide the brain based on different attributes—cell structure, function or some other characteristic—and there have been multiple different brain atlases developed over the years that have given different names to these divisions," Uddin said. "But we have to come to some common agreement if we want to talk across research groups and share findings."

The new open-source software, named the Network Correspondence Toolbox, allows researchers to plug in their brain imaging data and compare them to 16 of the most widely used brain atlases to determine their similarity.

Researchers and doctors have increasingly relied on brain imaging methods, such as MRIs, to understand what is underlying different symptoms and disorders. Similar to the design of major airports, certain areas of the brain may act as hubs that have more complex connections to other brain regions, Uddin said. The new tool can be used to better understand how these brain hubs interact and how alterations or damage may play a role in a number of different disorders or symptoms, Uddin said.


(A)
Input Data
Config File
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SPACE: fs_LR_32k
TYPE: Hard
Atlas List
•Yeo2011-17
•Gordon2017-17
•Glasser2016-360+Ji2019-12
•Shen2013-268-8
(B)
Atlases
Project to input data space
(C)
Network Correspondence (Dice Overlap)
• Compute Dice overlap between input data and all networks.
• Perform spin test to test the significance of Dice overlap.
(D)
Network Correspondence Summary
Network Clock
SalSubcor
FrontPar
DorsAttn
FrontPar
DorsAttn
FrontPar
Sal/VenAttnB
ControlA
ControlB
Dice Overlap Coefficient
1 Glasser2016-360+Ji2019-12
3 Gordon2017-17
2 Yeo2011-17
4 Shen2013-168-8
Network Radar
Somatomotor
FrontPar*
DorsAttn*
CingOperc
Default
Language
PostMulti
Visual2
Visual1
OrbitAffective
VentMulti
Auditory
Summary Table
Glasser2016-360+Ji2019-12
Name | Dice | P value
Visual1 | 0.0031 | 0.7423
Visual2 | 0.0072 | 0.8911
Somatomotor | 0.0001 | 0.997
CingOperc | 0.225 | 0.0999
DorsAttn | 0.2619 | 0.005*

Illustration of NCT usage to explore network correspondence between user-defined input data and a set of atlases. Credit: Nature Communications (2025). DOI: 10.1038/s41467-025-58176-9

Better understanding these broader connections may work to bolster individual-level, precision treatment for psychiatric or neurological disorders.

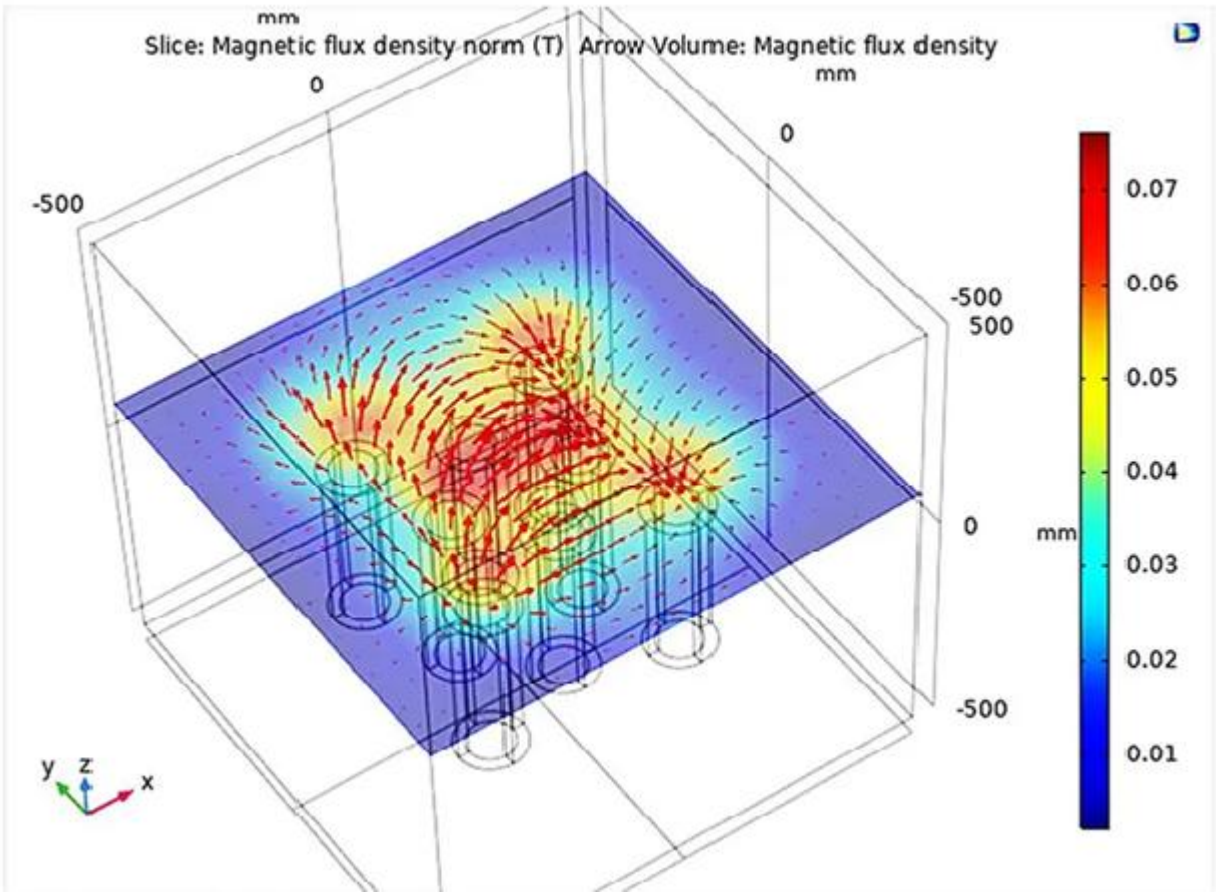
"I'm hoping people will use this tool to find commonalities across findings that might otherwise have been hidden because of the inconsistent naming," she says.

"It could change the way we think about dividing up the brain. If so many different groups are creating different atlases with slight differences, can this help inform us of the most common and reproducible patterns, and can we adopt more standards that build on those commonalities?"

More information: Ru Kong et al, A network correspondence toolbox for quantitative evaluation of novel neuroimaging results, *Nature Communications* (2025). DOI: 10.1038/s41467-025-58176-9

Provided by University of California, Los Angeles

Tiny robot tools powered by magnets could one day do brain surgery without cutting open the skull



An example magnetic flux density of the ENS. The field is created at the surgical site in the x-direction. Credit: Science Robotics (2025). DOI: 10.1126/scirobotics.adk4249

Most brain surgery requires doctors to remove part of the skull to access hard-to-reach areas or tumors. It's invasive, risky, and it takes a long time for the patient to recover.

We have developed new, tiny robotic surgical tools that may let surgeons perform "keyhole surgery" on the brain. Despite their small size, our tools can mimic the full range of motion of a surgeon's wrist, creating new possibilities for less-invasive brain surgery.

Force measurement setup for the magnetic gripper's wrist blocking force in the pushing direction (left), the magnetic gripper's jaw's closing force (middle), and the magnetic TSA forceps closing force (right). Credit: Science Robotics (2025). DOI: 10.1126/scirobotics.adk4249

Tiny tools for brain surgery

Robotic surgical tools (around 8 millimeters in diameter) have been used for decades in keyhole surgery for other parts of the body. The challenge has been making a tool small enough (3mm in diameter) for neurosurgery.

In a project led by the University of Toronto, where I was a postdoctoral fellow, we collaborated with The Hospital for Sick Children (SickKids) in Canada to develop a set of very small neurosurgery tools.

The tools are only about 3mm in diameter. In a paper published in *Science Robotics*, we demonstrated these tools could grip, pull and cut tissue.

Their extremely small size is possible as they are powered not by motors but by external magnetic fields.

Current robotic surgical tools are typically driven by cables connected to electric motors. They work in much the same way as human fingers, which are manipulated by tendons in the hand connected to muscles in the wrist.

However, pulleys smaller than several millimeters wide to control the instruments are weak and prone to friction, stretch and fracture. This creates challenges in scaling down the instruments, because of difficulties in making the parts of the system, assembling the mechanisms and managing friction in the cables.

Magnetic controls

The new robotic system consists of two parts. The first is the tiny tools themselves: a gripper, a scalpel and a set of forceps. The second part is what we call a "coil table," which is a surgical table with several electromagnetic coils embedded inside.

In this design, the patient would be positioned with their head on top of the embedded coils, and the robotic tools would be inserted into the brain via a small incision.

By altering the amount of electricity flowing into the coils, we can manipulate the magnetic fields, causing the tools to grip, pull or cut tissue as desired.

In open brain surgery, the surgeon relies on their own dexterous wrist to pivot the tools and tilt their tips to access hard-to-reach areas, such as removing a tumor inside the central cavity of the brain. Unlike other tools, our robotic neurosurgical tools can mimic this with "wristed" movements.

Surprising precision

We tested the tools in pre-clinical trials where we simulated the mechanical properties of the brain tissue they would need to work with. In some tests, we used pieces of tofu and raspberry placed inside a model of the brain.

We compared the performance of these magnetically operated tools with that of standard tools handled by trained surgeons.

We found the cuts made with the magnetic scalpel were consistent and narrow, with an average width of 0.3–0.4mm. That was even more precise than those from traditional hand tools, which ranged from 0.6 to 2.1mm.

As for the grippers, they could pick up the target 76% of the time.

From the lab to the operating room

We were surprised by how well the robotic tools performed. However, there is still a long way to go until this technology could help patients. It can take years, even decades, to develop medical devices, especially surgical robots.

This study is part of a broader project based on years of work led by Eric Diller from the University of Toronto, an expert on magnet-driven micro-robots.

Now, the team wants to make sure the robotic arm and magnetic system can fit comfortably in a hospital operating room. The team also wants to make it compatible with imaging systems such as fluoroscopy, which uses X-rays. After that, the tools may be ready for clinical trials.

We're excited about the potential for a new era of minimally invasive neurosurgical tools.

More information: Changyan He et al, Magnetically actuated dexterous tools for minimally invasive operation inside the brain, *Science Robotics* (2025). DOI: 10.1126/scirobotics.adk4249

Newly patented device could speed treatment for stroke patients

Steven Barlow, Corwin Moore Professor in special education and communication disorders, attaches the pTACS' thermoplastic tactile "touch" capsules to the hand of Jacob Greenwood, doctoral candidate in biological systems engineering. Credit: Loren Rye | Pixel Lab | University of Nebraska-Lincoln

Every year, more than 795,000 American adults suffer a stroke, and one in four adults worldwide will suffer a stroke in their lifetime. Early action can reduce rates of death and disability.

Now, a group of Husker researchers, led by Steven Barlow, has patented a groundbreaking frontline treatment—the pTACS Somatosensory Biomedical Device—for cerebrovascular accidents that is portable, making it a versatile product for use in rehabilitation clinics, emergency rooms and, potentially, transport ambulances.

"It's a very low-cost device," said Barlow, Corwin Moore Professor in special education and communication disorders, affiliate faculty member in biological systems engineering and resident faculty member in the Center for Brain, Biology and Behavior.

"That means centers and rehabilitation facilities all over the country and beyond will be able to use this technology. Stroke is the number one health problem worldwide, now surpassing other types of diseases."

The device includes a "smart" pneumatic controller and a microprocessor that is packaged inside a small black toolbox case and runs on rechargeable lithium-ion batteries—the same type and size of battery in a smartphone.

Barlow developed and fine-tuned the somatosensory therapy protocols through individualized research trials at the University of Nebraska–Lincoln.

The success of those clinical trials led Barlow and team member Jacob Greenwood, a doctoral candidate in biomedical engineering, to focus the design of the device on performance, portability and usability. Barlow and Greenwood share inventor status on the U.S. patent.

The pTACS biomedical device is a non-invasive method of brain stimulation. It utilizes rapidly compressed air pulses that are delivered through small plastic tubes into thermoplastic tactile "touch" capsules adhered to the hands, face, feet or other area of the skin to evoke repeated volleys of nerve responses.

The pTACS stimulation has been shown to increase blood flow in tissues of the cerebral cortex that are near the damaged area of the brain.

Animal models developed in the Frostig laboratory at the University of California, Irvine (Lay, Davis, Chen-Bee, Frostig, 2010) have shown that repeated somatosensory stimulation delivered during critical periods of recovery has the potential to save brain cells from death, preventing the formation of cerebral infarct.

"We take advantage of the inherent anatomy of the human brain—the way these sensory pathways are laid out—and by placing these cells on different parts of the body, we can selectively drive different parts of the brain with tremendous precision," Barlow said.

The toolbox containing the pTACS hardware and firmware is attached to a small laptop containing the software to run the machine, delivering a programmed set of air pulses based on research Barlow and his students have conducted in the

Barkley Speech-Language and Hearing Clinic and the Center for Brain, Biology and Behavior, and at other area institutions.

"The connected computer allows the user to select the protocol you want to run, and once that protocol is selected, it does everything," Greenwood said.

Receiving a patent for the pTACS is a step in the process of getting FDA approval for the device. Barlow said he expects to receive an additional patent for his stroke treatment protocol and is working with NUtech Ventures to create a biomedical startup to manufacture and commercialize the device. Barlow has previous success with developing and commercializing groundbreaking medical devices.

He developed and commercialized the NTrainer System 2.0, now sold and marketed internationally by Cardinal Health as the Kangaroo NTrainer System.

Frontline stroke treatment could be just one of the pTACS' therapeutic possibilities. Barlow and his team are developing and seeking funding to further research treatment protocols for post-stroke injury and speech-language therapy functions, including for those on the autism spectrum disorder.

"We've had some patients in the clinic, and they're at least six months post injury. Some of them are two and three years after their stroke, and we're still able to generate very significant improvements in their function," Barlow said.

"This therapy could be administered by a speech-language pathologist, physical therapist, nurse practitioner or someone with a neuroscience background.

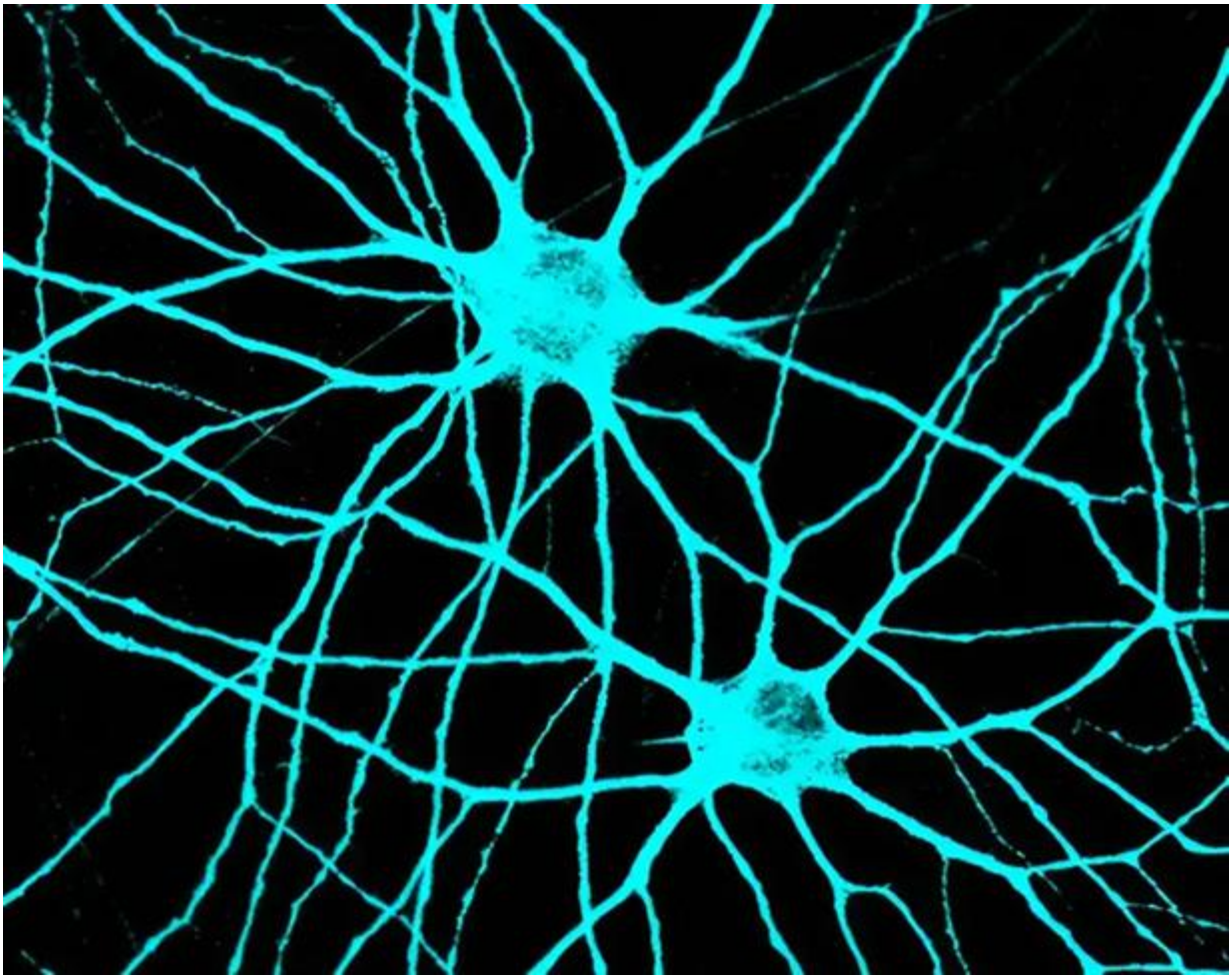
"In a current MRI study in collaboration with UNO Department of Biomechanics (Dr. Mukul Mukherjee) and UNMC Department of Neurology (Dr. Pierre Fayad), we use the pTACS device to drive mechanosensory nerve endings in the feet to stimulate the balance and gait system and activate related brain pathways."

Barlow anticipates more therapeutic uses for the pTACS device will be uncovered through additional research.

"It's got a really good trajectory," he said. "And we have a vibrant team. We have a lot of investigators, and many students interested in this."

Provided by University of Nebraska-Lincoln

Neuroscience research leverages stem cells to understand how neurons connect and communicate in the brain



Human neurons derived from stem cells by Assistant Professor Soham Chanda and his team at Colorado State University. Credit: Colorado State University© Provided by Medical Xpress

Newly published research from Colorado State University answers fundamental questions about cellular connectivity in the brain that could be useful in the development of treatments for neurological diseases like autism, epilepsy or schizophrenia.

The work, highlighted in the *Proceedings of the National Academy of Sciences,* focuses on how neurons in the brain transmit information between each other through highly specialized subcellular structures called synapses. These delicate structures are key to controlling many processes across the nervous

system via electrochemical signaling, and pathogenic mutations in the genes that impair their development can cause severe mental disorders.

Despite their important role in linking neurons across different brain regions, the way synapses form and function is still not well understood, said Assistant Professor Soham Chanda.

To answer that fundamental question, Chanda and his team in the Department of Biochemistry and Molecular Biology focused on a specific and important type of synapse called GABAergic. He said neuroscience researchers have long hypothesized that these synapses might form because of a release of GABA and the corresponding sensing activity between two neurons in proximity. However, research in the paper now shows that these synapses can begin to develop autonomously and apart from that neuronal communication, mainly due to the scaffolding action of a protein called Gephyrin. These findings clarify the key mechanisms of synaptic formation, which might allow researchers to further focus on synapse dysfunction and health treatment options.

Chanda's team used human neurons derived from stem cells to develop a model of the brain that could rigorously test these relationships. Using a gene-editing tool called CRISPR-Cas9, they were able to genetically manipulate the system and confirm the role of Gephyrin in the synapse formation process.

"Our study shows that even if a pre-synaptic neuron is not releasing GABA, the post-synaptic neuron can still put together the necessary molecular machineries prepared to sense GABA," Chanda said. "We used a gene-editing tool to remove the Gephyrin protein from neurons, which largely reduced this autonomous assembly of synapses—confirming its important role irrespective of neuronal communication."

Using stem cells to advance understanding of neuron and synapse formation

Neuroscientists have traditionally used rodent systems to study these synaptic connections in the brain. While that provides a suitable model, Chanda and his team were interested in testing synapse properties in a human cellular environment that could eventually be more easily translated into treatments.

To achieve this, his team cultivated human stem cells to form brain cells that could mimic the properties of human neurons and synapses. They then conducted extensive high-resolution imaging of these neurons and tracked their electrical activities to understand synaptic mechanisms.

Chanda said that several mutations in the Gephyrin protein have been associated with neurological disorders like epilepsy, which alters neuronal excitability in the human brain. That makes understanding its basic cellular function an important first step towards treatment and prevention.

"Now that we better understand how these synaptic structures interact and organize, the next question will be to elucidate how defects in their relationships can lead to disease and identify the ways one can predict or intervene in that process," he said.

More information: Etta Carricaburu et al, Gephyrin promotes autonomous assembly and synaptic localization of GABAergic postsynaptic components without presynaptic GABA release, *Proceedings of the National Academy of Sciences* (2024). DOI: 10.1073/pnas.2315100121

Provided by Colorado State University

Adults still develop new neurons: but what are they for?

Published by Cédric, December 17, 2024

Article author: Cédric DEPOND

Source: Cell Stem Cell

Your brain, far from being fixed in adulthood, continues to renew itself. Researchers reveal that the birth of new neurons in adults plays a key role in learning. This discovery overturns our understanding of human cognitive mechanisms.

The brain, the conductor of our body, relies on a network of neurons largely acquired at birth. However, certain regions continue to produce neurons throughout life. This process, though rare and limited, is called neurogenesis.

For a long time, scientists debated the true importance of this adult neurogenesis. Earlier studies observed a decrease in new neurons among patients with diseases such as Alzheimer's or epilepsy. This phenomenon was correlated with cognitive disorders, but the precise cause remained undetermined.

Recently, researchers at the University of Southern California delved into this mystery by studying patients with drug-resistant epilepsy. These patients, undergoing surgical procedures, provide a unique opportunity to collect and analyze human brain tissue.

The results are striking: new neurons in adults appear directly associated with verbal learning. These cells seem to enhance listening, understanding, and retaining information shared in conversations. This essential function, ironically, differs from findings in mice, where neurogenesis primarily supports spatial orientation.

To reach these conclusions, researchers analyzed specific markers in the brain tissue of patients. They discovered that fewer new neurons in the hippocampus correlate with a marked decline in verbal learning and memory capabilities.

This discovery opens new avenues of hope. Researchers believe stimulating neurogenesis could improve cognitive abilities in older adults or individuals with neurological disorders. Moreover, physical exercise is thought to have significant potential impacts on the production of new neurons in patients with epilepsy.

However, these approaches remain experimental. Researchers emphasize the need to deepen the study of neurogenesis directly in humans, which may differ from animal models. In the long run, these studies could transform our understanding of neurodegenerative diseases and aging mechanisms. The brain's renewal, even if limited, may well become a cornerstone of cognitive health.

What is adult neurogenesis?

Adult neurogenesis refers to the process of forming new neurons in the brain after birth, including during adulthood. Contrary to popular belief, the adult brain is not fixed but retains the ability to produce nerve cells, albeit in a limited manner.

This phenomenon primarily occurs in two regions: the hippocampus, involved in memory and learning, and the olfactory bulb, responsible for the sense of smell. These areas house stem cells capable of transforming into functional neurons.

Adult neurogenesis plays a key role in certain cognitive functions like learning, verbal memory, and spatial navigation. Its activity tends to decline with age or in cases of neurological diseases.

Recent studies suggest that stimulating neurogenesis through physical exercise or therapeutic approaches could potentially slow cognitive decline associated with aging or diseases like Alzheimer's.

Neuroscience mystery solved? How our brains use experiences to make sense of time

Neurons replay the past to predict the future

In a nutshell

- Scientists observed individual brain cells learning and encoding patterns of experience, revealing how neurons create "mental maps" of time and sequences
- The brain uses similar mechanisms to track time as it does to navigate space— specialized neurons gradually adapt to recognize temporal relationships between events
- When neurons learn these patterns, they maintain their new firing behavior even after sequences become random again, and can rapidly "replay" learned sequences during rest periods

LOS ANGELES —Time flows as a constant stream of moments, but your brain sees patterns in this flow. Now, scientists have discovered exactly how individual neurons learn to recognize and predict these patterns, providing the first direct evidence of how our brains map out the structure of time.

The study, published in *Nature*, was conducted by researchers at UCLA Health. It required recording the activity of individual neurons in patients who had electrodes implanted in their brains for epilepsy treatment. These recordings offer a rare glimpse into how individual brain cells behave during learning and memory formation—something that's impossible to observe with standard brain imaging techniques.

"Recognizing patterns from experiences over time is crucial for the human brain to form memory, predict potential future outcomes, and guide behaviors," says Dr. Itzhak Fried, director of epilepsy surgery at UCLA Health, in a statement.

“But how this process is carried out in the brain at the cellular level had remained unknown – until now.”

Prior to the main experiment, researchers needed to identify which images would trigger strong neural responses in each participant. They showed participants about 120 different pictures over 40 minutes, including images of celebrities, landmarks, and other subjects chosen partly based on each person’s interests. Based on how brain cells responded, researchers selected six specific images for each participant to use in the main experiment.

Using past experiences, the brain can form patterns to make predictions about the future. (metamorworks/Shutterstock)

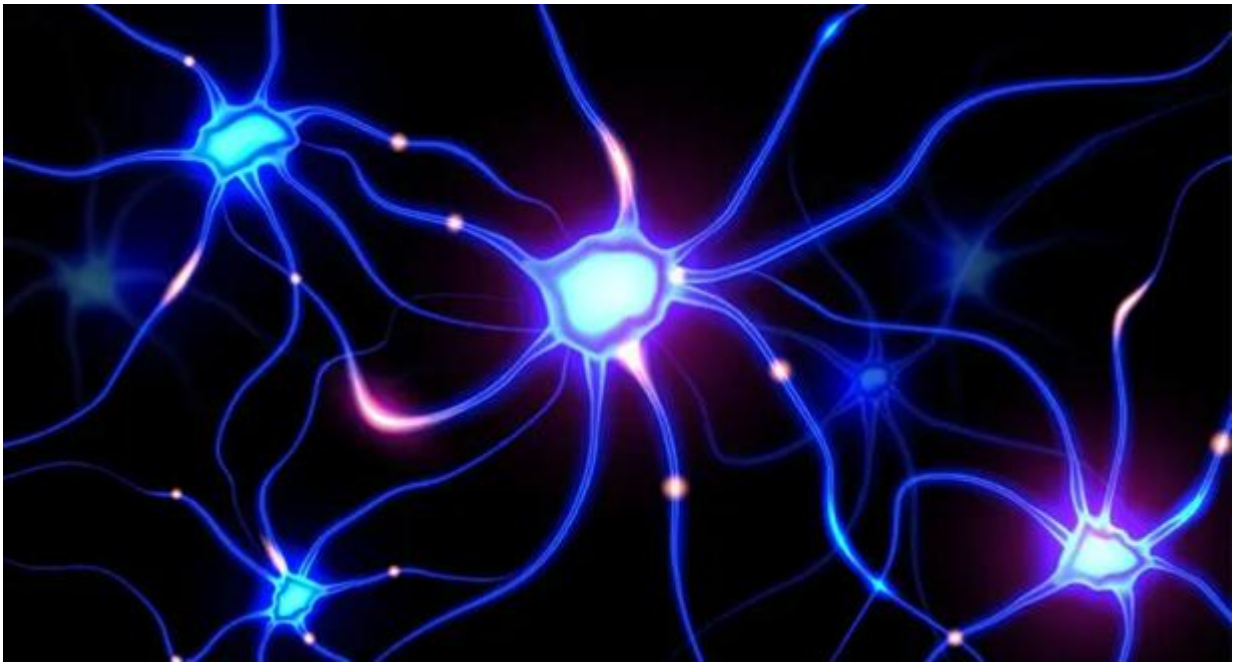
The main study had three phases. In the first phase, images appeared in random order while participants performed simple tasks, like identifying whether the person shown was male or female. During the middle phase, images appeared in sequences that followed specific rules, though participants weren’t told about these rules. Instead, they focused on a new task: determining whether each image was shown normally or in a mirror image. The final phase returned to random sequences and the original gender identification task.

The sequence rules were based on what researchers called a pyramid graph. Six points were arranged in a triangle shape, with each point representing one of the selected images. Lines connected certain points, indicating which images could

appear after others. Some images were directly connected, like neighboring points on the graph. Others required taking an indirect path through multiple points to get from one to another.

What makes this study particularly fascinating is that it revealed how individual neurons adapted as participants became familiar with these sequences. At first, a neuron would respond strongly to just one specific image. But over time, these same neurons began responding to images that frequently appeared close together in the sequence, essentially mapping out the temporal relationships between different images.

The brain's ability to encode these temporal patterns shares remarkable similarities with how it represents physical space. Previous research discovered that certain neurons act as "place cells," firing when an animal reaches specific locations, while others function as "grid cells" that help measure distances. The new study shows the brain uses comparable mechanisms to map out sequences of events and experiences.



An illustration of a neuron, one of the brain's key cells for processing information. (Vector_Artist/Shutterstock)

This research also builds on earlier discoveries about "concept cells," neurons that respond to specific individuals, places, or objects. These specialized brain cells appear to be fundamental building blocks of memory. The new findings show

how these neurons work together to create structured representations of our experiences through time.

The researchers discovered that this neural mapping created what they call a "successor representation," a predictive map that considers not just immediate connections but likely future events. Rather than simply linking one moment to the next, your brain builds a broader model of likely future possibilities based on learned patterns.

"This study shows us for the first time how the brain uses analogous mechanisms to represent what are seemingly very different types of information: space and time," explains Fried. "We have demonstrated at the neuronal level how these representations of object trajectories in time are incorporated by the human *hippocampal-entorhinal system*."

During breaks between testing phases, researchers observed "replay" events, moments when neurons would rapidly rehearse the learned sequences in a compressed timeframe. This neural replay happened in milliseconds, suggesting a mechanism for consolidating learned patterns into memory.

Understanding how the brain encodes temporal patterns goes beyond basic science. The findings could help develop new treatments for memory disorders and advance the design of brain-computer interfaces. They may also inform artificial intelligence systems that aim to process sequential information in ways that mirror human cognition.

Paper Summary

Methodology

The study used a clever multi-phase design to observe how neurons learn temporal patterns. First, researchers identified which images triggered strong neural responses in each participant through a screening phase showing 120 different pictures. They then selected six images per participant for the main experiment. The study consisted of three phases: pre-exposure with random sequences, exposure phases where images followed specific rules based on a

pyramid graph, and post-exposure returning to random sequences. Participants performed simple tasks like gender identification or detecting mirrored images, while researchers recorded activity from individual neurons through implanted electrodes. This experimental setup allowed researchers to observe how neural responses changed as participants unconsciously learned the underlying pattern structure.

Results

The study revealed several important findings. Individual neurons that initially responded strongly to single images began responding to multiple images that often appeared close together in sequences. The brain's representation of these temporal patterns matched a "successor representation" that encoded not just immediate connections but likely future states. These neural patterns persisted even when sequences became random again, showing lasting learning had occurred. Researchers also observed rapid "replay" of learned sequences during rest periods, suggesting a mechanism for memory consolidation.

Limitations

While groundbreaking, the study has some inherent limitations. All participants were epilepsy patients with implanted electrodes, which might not perfectly represent typical brain function. The sample included 17 patients across 21 recording sessions – a substantial number for this type of invasive recording but still relatively small for broader generalizations. The temporal patterns used were necessarily simpler than the complex sequences we encounter in daily life. Additionally, participants demonstrated limited explicit knowledge of the underlying patterns, suggesting the learning was largely unconscious.

Discussion and Takeaways

This research provides unprecedented insight into how individual human neurons encode temporal patterns. The findings demonstrate striking parallels between how the brain represents spatial and temporal relationships, suggesting common neural mechanisms for mapping both domains. The discovery of persistent neural

changes and replay events helps explain how the brain consolidates and maintains learned patterns. These insights could inform development of memory enhancement devices and artificial intelligence systems designed to process sequential information more like the human brain.

Funding and Disclosures

The research was supported by the Marie Sklodowska-Curie fellowship, National Institute of Neurological Disorders and Stroke grants, and the Foundation for Science and Technology. The study was conducted at UCLA Health, with Dr. Itzhak Fried serving as senior author and Pawel Tacikowski as lead author, working alongside co-authors Guldamla Kalendar and Davide Ciliberti.

Publication Information

"Human hippocampal and entorhinal neurons encode the temporal structure of experience" was published in *Nature*, Volume 635, on November 7, 2024. The research represents a collaboration between UCLA, Karolinska Institute, and the University of Coimbra.

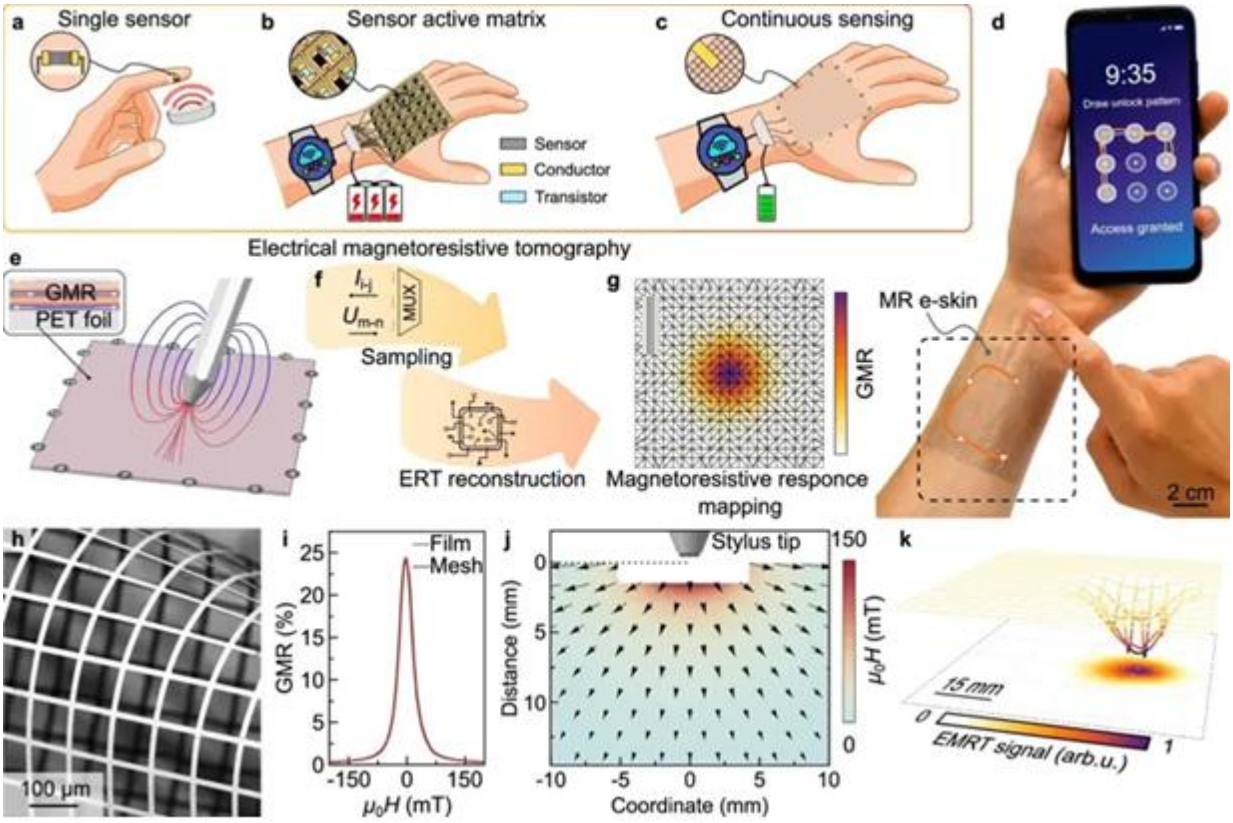
Smartest electronic skin with ‘brain’ could be magnetic miracle for humans, robots

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.

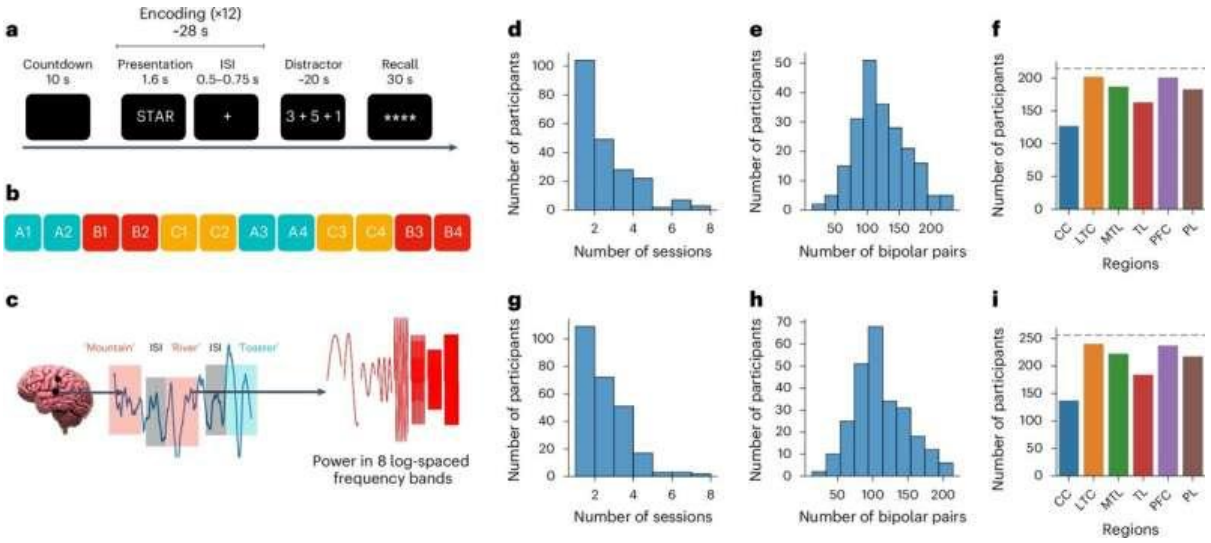
There could be many other possibilities. This e-skin could soon become commercially available and change the way we interact with everything around us.

The study is published in the journal *Nature Communications*.

MARCH 30, 2025

Short-term reactivation of brain between encoding of memories enhances recall, study finds

by Ingrid Fadelli , Medical Xpress



Experimental tasks and methods for experiments 1 and 2. Credit: *Nature Neuroscience* (2025). DOI: 10.1038/s41593-025-01884-8

Past neuroscience and psychology studies have shown that after the human brain encodes specific events or information, it can periodically reactivate them to facilitate their retention, via a process known as memory consolidation. The reactivation of memories has been specifically studied in the context of sleep or rest, with findings suggesting that during periods of inactivity, the brain reactivates specific memories, allowing people to remember them in the long term.

Researchers at the University of Pennsylvania and other institutions in the United States recently conducted a study exploring the possibility that the brain engages in a similar reactivation process during wakefulness to store important information for shorter periods of time. Their findings, published in *Nature Neuroscience*, suggest that the spontaneous reactivation of specific stimuli in the brain during the brief intervals between their encoding predicts the accuracy with which people remember them at the end of a memory task.

"Mike Kahana and I were both quite interested in the long history of thinking about rehearsal and its effects on the way in which people later recalled things," Dr. David Halpern, the first author of the paper, told Medical Xpress. "Rehearsal is challenging to study since people often do it without any overt behavior (unless we ask them to rehearse out loud)."

Dr. Michael J. Kahana's lab at the University of Pennsylvania has been conducting studies related to memory processes for some time. This led to the creation of a dataset that includes memory task performance and matching intracranial electroencephalography (EEG) recordings from several people, offering insight into what happens in the brain while people attempt to remember information for short periods of time.

"We decided to try to look at when neural activity related to specific words seemed to be reactivated while they were looking at other words and see if that looked like what theorists in psychology thought was going on," said Dr. Halpern. "In addition, there is this parallel literature on consolidation in neuroscience that also suggested that reactivation was key to understanding what gets remembered later."

Many previous studies and theoretical psychology models suggest that memory consolidation processes primarily take place during sleep and over extended periods of rest. During these periods, the brain is not actively engaged in everyday activities and external perceptions, but rather focused on internal thoughts or processes.

"In addition, past works suggest that certain neurotransmitters are involved in long timescales, much longer than the time between two-word presentations," said Dr. Halpern. "This meant that looking at neural reinstatement in our data would also have interesting implications for those theories as well."

As part of their study, the researchers analyzed the data collected by the Kahana Lab, which measured neural activity using intracranial EEG. This is a technique that relies on implanted electrodes, which some patients diagnosed with epilepsy are already exposed to as part of their treatment (i.e., to identify the brain tissue that should be surgically removed to diminish or entirely stop their epileptic seizures).

"These patients need to wait in the hospital until they get enough measurements to determine the source, so a network of our research assistants across the country asked them if they would be willing to do a memory task while their neural activity is being recorded," explained Dr. Halpern.

"The task we usually use is called free recall: we ask the patients to look at a sequence of words on a screen and then, after a short delay, recall as many of them as they can in any order."

Dr. Halpern, Dr. Kahana and their collaborators combined intracranial EEG recordings collected while patients were completing a short-term memory task with their performance on the task (i.e., what they remembered and the order in which they remembered stimuli). The study participants' ability to recall information and the order in which they remember it offers valuable insight into how memories are organized in their brains.

"Firstly, we found that there seems to be some process happening involving reinstatement of neural activity on a sub-second scale that is related to later memory performance," said Dr. Halpern.

"This is a way in which the brain/mind can, after having an experience, make it more likely to be remembered later and perhaps alter the way in which it is remembered. It is interesting that the processes are, at first glance, quite similar to what we think is going on during sleep."

Overall, the initial findings gathered by this team of researchers suggest that the brain also re-activates stimuli that we are trying to remember over short periods of time while we are awake. Further research could help to better understand the brain re-activation processes they observed and determine how they differ from those associated with memory consolidation during sleep or rest.

In the future, these results could also help devise interventions aimed at improving people's ability to remember information in the short-term, which could be beneficial for both students and people diagnosed with memory disorders. Dr. Halpern has now left the Kahana Lab and now works in another research lab that is exploring the connections between memory and decision-making.

"I am very interested in the way in which rehearsal and reinstatement might be involved in the evaluation process that leads us to make a choice," added Dr. Halpern. "Another question I am quite interested in exploring is, if we are routinely (perhaps subconsciously) rehearsing our past experiences, how does our brain keep these separate from our ongoing veridical perceptual experience?

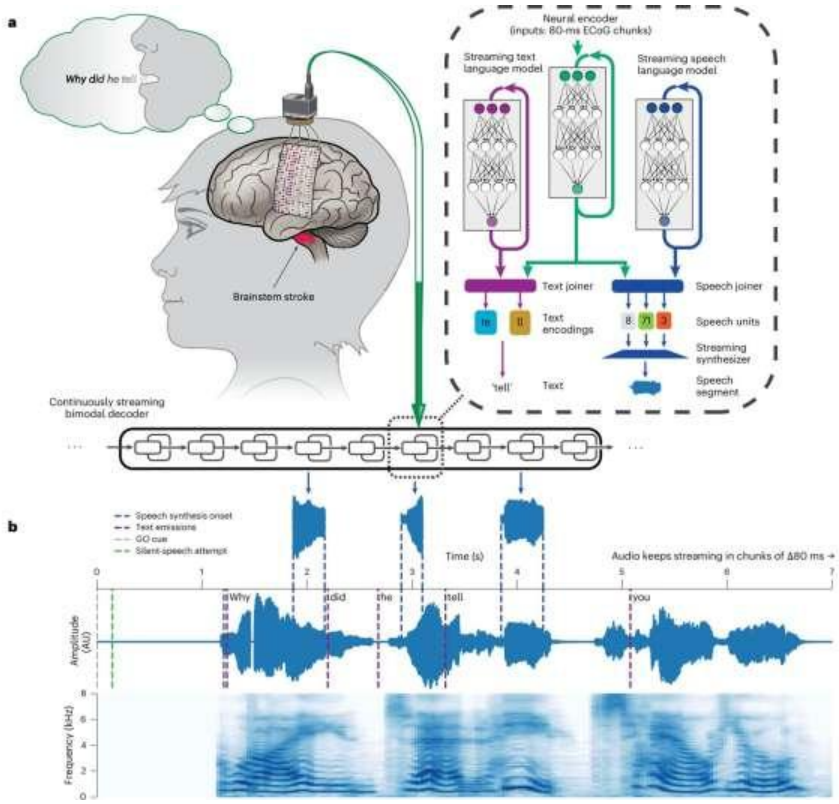
"In theory, this should cause some interference in terms of remembering the order in which things happened, but this doesn't seem to be the case, even in our data."

More information: David J. Halpern et al, Study-phase reinstatement predicts subsequent recall, *Nature Neuroscience* (2025). DOI: 10.1038/s41593-025-01884-8.
Journal information: Nature Neuroscience

MARCH 31, 2025

Brain-to-voice interface converts thoughts to speech in near-real time

by University of California - Berkeley



Overview of a naturalistic streaming silent-speech neuroprosthesis. Credit: *Nature Neuroscience* (2025). DOI: 10.1038/s41593-025-01905-6

Marking a breakthrough in the field of brain-computer interfaces (BCIs), a team of researchers from UC Berkeley and UC San Francisco has unlocked a way to restore naturalistic speech for people with severe paralysis.

This work solves the long-standing challenge of latency in speech neuroprostheses, the time lag between when a subject attempts to speak and when sound is produced. Using recent advances in artificial intelligence-based modeling, the researchers developed a streaming method that synthesizes brain signals into audible speech in near-real time.

As reported in *Nature Neuroscience*, this technology represents a critical step toward enabling communication for people who have lost the ability to speak.

"Our streaming approach brings the same rapid speech decoding capacity of devices like Alexa and Siri to neuroprostheses," said Gopala Anumanchipalli, Robert E. and Beverly A. Brooks Assistant Professor of Electrical Engineering and Computer Sciences at UC Berkeley and co-principal investigator of the study.

"Using a similar type of algorithm, we found that we could decode neural data and, for the first time, enable near-synchronous voice streaming. The result is more naturalistic, fluent speech synthesis."

"This new technology has tremendous potential for improving quality of life for people living with severe paralysis affecting speech," said neurosurgeon Edward Chang, senior co-principal investigator of the study. Chang leads the clinical trial at UCSF that aims to develop speech neuroprosthesis technology using high-density electrode arrays that record neural activity directly from the brain surface.

"It is exciting that the latest AI advances are greatly accelerating BCIs for practical real-world use in the near future."

A demonstration of online naturalistic streaming speech synthesis with synchronized text decoding from brain activity. Credit: *Nature Neuroscience* (2025). DOI: 10.1038/s41593-025-01905-6

The researchers also showed that their approach can work well with a variety of other brain sensing interfaces, including microelectrode arrays (MEAs) in which electrodes penetrate the brain's surface, or non-invasive recordings (sEMG) that use sensors on the face to measure muscle activity.

"By demonstrating accurate brain-to-voice synthesis on other silent-speech datasets, we showed that this technique is not limited to one specific type of device," said Kaylo Littlejohn, Ph.D. student at UC Berkeley's Department of Electrical Engineering and Computer Sciences and co-lead author of the study. "The same algorithm can be used across different modalities provided a good signal is there."

Decoding neural data into speech

According to study co-lead author Cheol Jun Cho, UC Berkeley Ph.D. student in electrical engineering and computer sciences, the neuroprosthesis works by sampling neural data from the motor cortex, the part of the brain that controls speech production, then uses AI to decode brain function into speech.

"We are essentially intercepting signals where the thought is translated into articulation and in the middle of that motor control," he said. "So what we're decoding is after a thought has happened, after we've decided what to say, after we've decided what words to use and how to move our vocal-tract muscles."

To collect the data needed to train their algorithm, the researchers first had Ann, their subject, look at a prompt on the screen—like the phrase: "Hey, how are you?"—and then silently attempt to speak that sentence.

"This gave us a mapping between the chunked windows of neural activity that she generates and the target sentence that she's trying to say, without her needing to vocalize at any point," said Littlejohn.

Because Ann does not have any residual vocalization, the researchers did not have target audio, or output, to which they could map the neural data, the input. They solved this challenge by using AI to fill in the missing details.

"We used a pretrained text-to-speech model to generate audio and simulate a target," said Cho. "And we also used Ann's pre-injury voice, so when we decode the output, it sounds more like her."

Streaming speech in near-real time

In their previous BCI study, the researchers had a long latency for decoding, about an 8-second delay for a single sentence. With the new streaming approach, audible output can be generated in near-real time, as the subject is attempting to speak.

To measure latency, the researchers employed speech detection methods, which allowed them to identify the brain signals indicating the start of a speech attempt.

"We can see relative to that intent signal, within 1 second, we are getting the first sound out," said Anumanchipalli. "And the device can continuously decode speech, so Ann can keep speaking without interruption."

This greater speed did not come at the cost of precision. The faster interface delivered the same high level of decoding accuracy as their previous, non-streaming approach.

"That's promising to see," said Littlejohn. "Previously, it was not known if intelligible speech could be streamed from the brain in real time."

Anumanchipalli added that researchers don't always know whether large-scale AI systems are learning and adapting, or simply pattern-matching and repeating parts of the training data. So the researchers also tested the real-time model's ability to synthesize words that were not part of the training dataset vocabulary—in this case, 26 rare words taken from the NATO phonetic alphabet, such as "Alpha," "Bravo," "Charlie" and so on.

"We wanted to see if we could generalize to the unseen words and really decode Ann's patterns of speaking," he said. "We found that our model does this well, which shows that it is indeed learning the building blocks of sound or voice."

Ann, who also participated in the 2023 study, shared with researchers how her experience with the new streaming synthesis approach compared to the earlier study's text-to-speech decoding method.

"She conveyed that streaming synthesis was a more volitionally controlled modality," said Anumanchipalli. "Hearing her own voice in near-real time increased her sense of embodiment."

Future directions

This latest work brings researchers a step closer to achieving naturalistic speech with BCI devices, while laying the groundwork for future advances.

"This proof-of-concept framework is quite a breakthrough," said Cho. "We are optimistic that we can now make advances at every level. On the engineering side, for example, we will continue to push the algorithm to see how we can generate speech better and faster."

The researchers also remain focused on building expressivity into the output voice to reflect the changes in tone, pitch or loudness that occur during speech, such as when someone is excited.

"That's ongoing work, to try to see how well we can actually decode these paralinguistic features from brain activity," said Littlejohn. "This is a longstanding problem even in classical audio synthesis fields and would bridge the gap to full and complete naturalism."

More information: Edward F. Chang, A streaming brain-to-voice neuroprosthesis to restore naturalistic communication, *Nature Neuroscience* (2025). DOI: 10.1038/s41593-025-01905-6. www.nature.com/articles/s41593-025-01905-6
Journal information: Nature Neuroscience
Provided by University of California - Berkeley

MARCH 31, 2025

Brain implant turns thoughts into speech in near real-time

by Daniel Lawler

Scientists brain-computer interfaces could give back a voice to people who have lost the ability to communicate.

A brain implant using artificial intelligence was able to turn a paralyzed woman's thoughts into speech almost simultaneously, US researchers said Monday.

Though still at the experimental stage, the latest achievement using an implant linking brains and computers raised hopes that these devices could allow people who have lost the ability to communicate to regain their voice.

The California-based team of researchers had previously used a brain-computer interface (BCI) to decode the thoughts of Ann, a 47-year-old with quadriplegia, and translate them into speech.

However there was an eight-second delay between her thoughts and the speech being read aloud by a computer.

This meant a flowing conversation was still out of reach for Ann, a former high school math teacher who has not been able to speak since suffering a stroke 18 years ago.

But the team's new model, revealed in the journal *Nature Neuroscience*, turned Ann's thoughts into a version of her old speaking voice in 80-millisecond increments.

"Our new streaming approach converts her brain signals to her customized voice in real time, within a second of her intent to speak," senior study author Gopala Anumanchipalli of the University of California, Berkeley told AFP.

Ann's eventual goal is to become a university counselor, he added.

"While we are still far from enabling that for Ann, this milestone takes us closer to drastically improving the quality of life of individuals with vocal paralysis."

'Excited to hear her voice'

For the research, Ann was shown sentences on a screen—such as "You love me then"—which she would say to herself in her mind.

Then her thoughts would be converted into her voice, which the researchers built up from recordings of her speaking before she was injured.

Ann was "very excited to hear her voice, and reported a sense of embodiment," Anumanchipalli said.

The BCI intercepts brain signals "after we've decided what to say, after we've decided what words to use and how to move our vocal tract muscles," study co-author Cheol Jun Cho explained in a statement.

The model uses an artificial intelligence method called deep learning that was trained on Ann previously attempting to silently speak thousands of sentences.

It was not always accurate—and still has a limited vocabulary of 1,024 words.

Patrick Degenaar, a neuroprosthetics professor at the UK's Newcastle University not involved in the study, told AFP that this is "very early proof of principle" research.

But it is still "very cool," he added.

Degenaar pointed out that this system uses an array of electrodes that do not penetrate the brain, unlike the BCI used by billionaire Elon Musk's Neuralink firm.

The surgery for installing these arrays is relatively common in hospitals for diagnosing epilepsy, which means this technology would be easier to roll out en masse, he added.

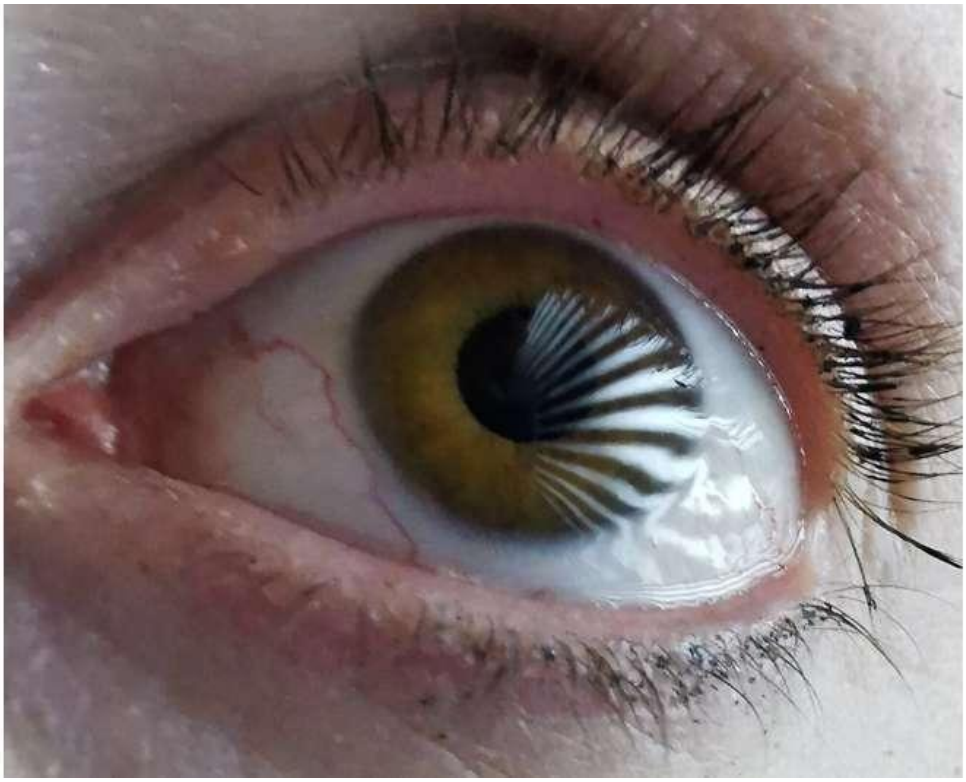
With proper funding, Anumanchipalli estimated the technology could be helping people communicate in five to 10 years.

More information: Edward F. Chang, A streaming brain-to-voice neuroprosthesis to restore naturalistic communication, *Nature Neuroscience* (2025). DOI: 10.1038/s41593-025-01905-6. www.nature.com/articles/s41593-025-01905-6
Journal information: Nature Neuroscience

APRIL 1, 2025

'Superhuman vision': Powerful 3D imaging technology paves way for next-generation eye-tracking

by University of Arizona



A pattern of distorted lines is visible as a reflection in this close-up view of a human eye. By observing the deformation of illumination patterns reflected off the eye's surface, researchers in Willomitzer's group can capture gaze direction information from tens of thousands of surface points instead of the dozen or so used by conventional eye-tracking methods. Credit: Florian Willomitzer

Eye tracking plays a critical role in the latest virtual and augmented reality headsets and is an important technology in the entertainment industry, scientific research, medical and behavioral sciences, automotive driving assistance and industrial engineering. Tracking the movements of the human eye with high accuracy, however, is a daunting challenge.

Researchers at the University of Arizona Wyant College of Optical Sciences have now demonstrated an innovative approach that could revolutionize eye-tracking applications.

Their study, published in *Nature Communications*, finds that integrating a powerful 3D imaging technique known as deflectometry with advanced computation has the potential to significantly improve state-of-the-art eye tracking technology.

"Current eye-tracking methods can only capture directional information of the eyeball from a few sparse surface points, about a dozen at most," said Florian Willomitzer, associate professor of optical sciences and principal investigator of the study.

"With our deflectometry-based method, we can use the information from more than 40,000 surface points, theoretically even millions, all extracted from only one single, instantaneous camera image."

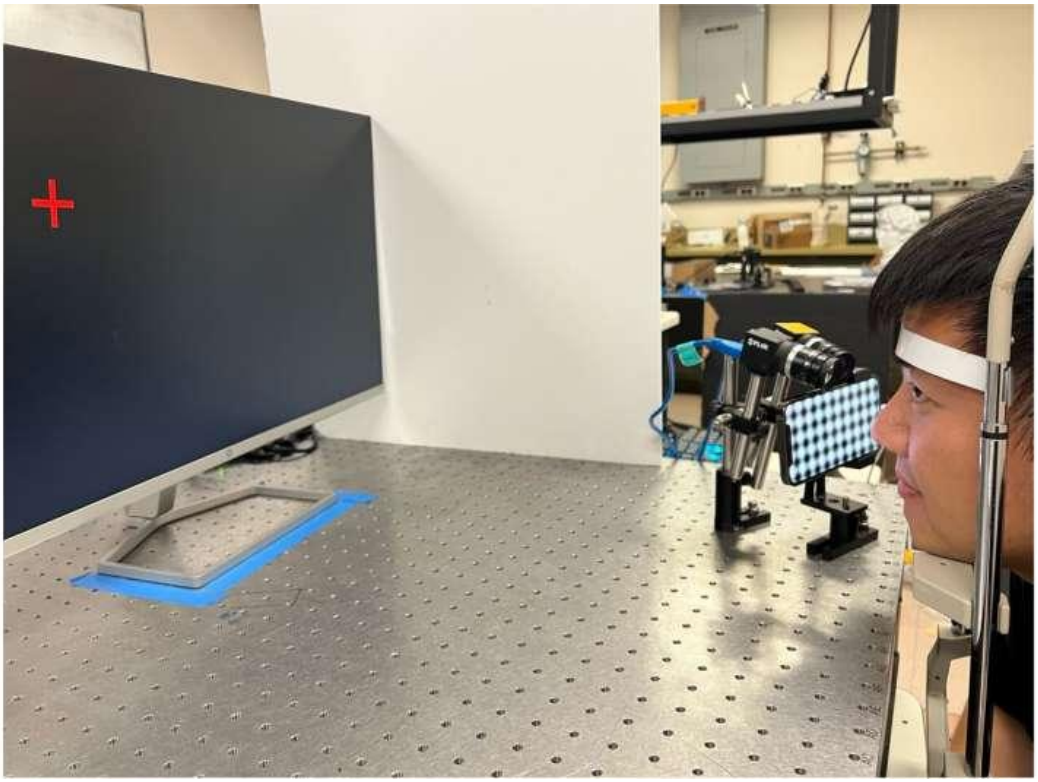
"More data points provide more information that can be potentially used to significantly increase the accuracy of the gaze direction estimation," said Jiazhang Wang, postdoctoral researcher in Willomitzer's lab and the study's first author.

"This is critical, for instance, to enable next-generation applications in virtual reality. We have shown that our method can easily increase the number of acquired data points by a factor of more than 3,000, compared to conventional approaches."

Deflectometry is a 3D imaging technique that allows for the measurement of reflective surfaces with very high accuracy. Common applications of deflectometry include scanning large telescope mirrors or other high-performance optics for the slightest imperfections or deviations from their prescribed shape.

Leveraging the power of deflectometry for applications outside the inspection of industrial surfaces is a major research focus of Willomitzer's research group in the U of A Computational 3D Imaging and Measurement Lab. The team pairs deflectometry with advanced computational methods typically used in computer vision research.

The resulting research track, which Willomitzer calls "computational deflectometry," includes techniques for the analysis of paintings and artworks, tablet-based 3D imaging methods to measure the shape of skin lesions, and eye tracking.



Jiazhang Wang, postdoctoral researcher in Willomitzer's lab and the study's first author, demonstrates the experimental setup: A stereo camera records reflections of a light grid reflected off the eye, as the study subject observes a point (red cross) moving on a screen. Credit: Florian Willomitzer

"The unique combination of precise measurement techniques and advanced computation allows machines to 'see the unseen,' giving them 'superhuman vision' beyond the limits of what humans can perceive," Willomitzer said.

In this study, the team conducted experiments with human participants and a realistic, artificial eye model. The team measured the study subjects' viewing direction and was able to track their gaze direction with accuracies between 0.46 and 0.97 degrees. When tested on the artificial eye model, the error was around just 0.1 degrees.

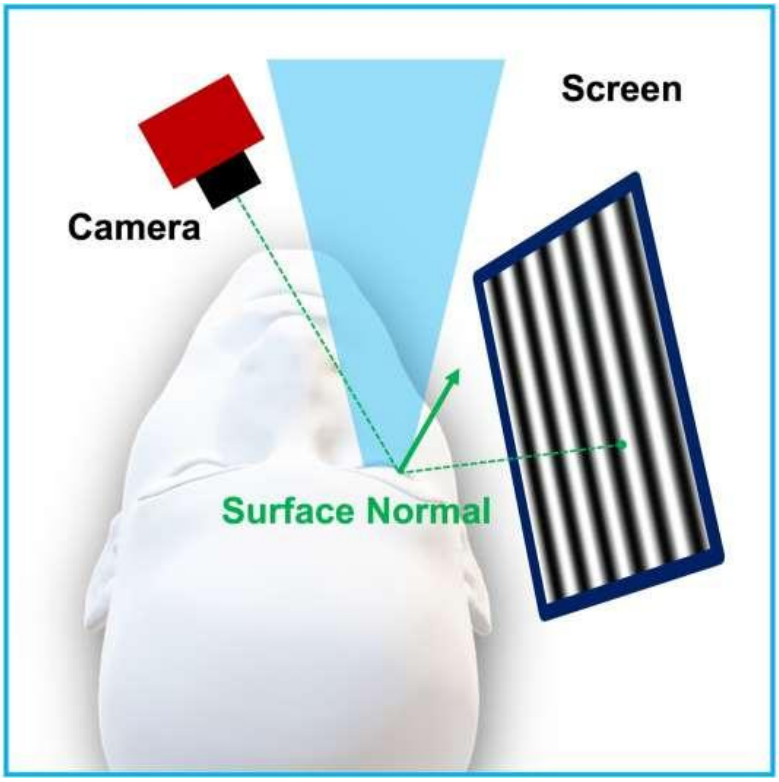
Instead of depending on a few infrared point light sources to acquire information from eye surface reflections, the new method uses a screen displaying known structured light patterns as the illumination source. Each of the more than 1 million pixels on the screen can thereby act as an individual point light source.

By analyzing the deformation of the displayed patterns as they reflect off the eye surface, the researchers can obtain accurate and dense 3D surface data from both the cornea, which overlays the pupil, and the white area around the pupil, known as the sclera, Wang explained.

Subscribe
"Our computational reconstruction then uses this surface data together with known geometrical constraints about the eye's optical axis to accurately predict the gaze direction," he said.

In a previous study, the team has already explored how the technology could seamlessly integrate with virtual reality and augmented reality systems by potentially using a fixed embedded pattern in the headset frame or the visual content of the headset itself—be it still images or video—as the pattern that is reflected from the eye surface.

This can significantly reduce system complexity, the researchers say. Moreover, future versions of this technology could use infrared light instead of visible light, allowing the system to operate without distracting users with visible patterns.



How the technique works: A camera records patterns of light as they reflect off the surface of the eye. An algorithm uses a so-called surface normal vector – the direction that is perpendicular to the eye surface – to measure the eye shape, which can then be used to estimate gaze direction. "FoV" stands for "field of view." Credit: Florian Willomitzer and Jiazhang Wang

"To obtain as much direction information as possible from the eye's cornea and sclera without any ambiguities, we use stereo-deflectometry paired with novel surface optimization algorithms," Wang said. "The technique determines the gaze without making strong assumptions about the shape or surface of the eye, as some other methods do, because these parameters can vary from user to user."

In a desirable "side effect," the new technology creates a dense and accurate surface reconstruction of the eye, which could potentially be used for on-the-fly diagnosis and correction of specific eye disorders in the future, the researchers added.

Aiming for the next technology leap

While this is the first time deflectometry has been used for eye tracking—to the researchers' knowledge—Wang said, "It is encouraging that our early implementation has already demonstrated accuracy comparable to or better than commercial eye-tracking systems in real human eye experiments."

With a pending patent and plans for commercialization through Tech Launch Arizona, the research paves the way for a new era of robust and accurate eye-tracking. The researchers believe that with further engineering refinements and algorithmic optimizations, they can push the limits of eye tracking beyond what has been previously achieved using techniques fit for real-world application settings.

Next, the team plans to embed other 3D reconstruction methods into the system and take advantage of artificial intelligence to further improve the technique.

"Our goal is to close in on the 0.1-degree accuracy levels obtained with the model eye experiments," Willomitzer said. "We hope that our new method will enable a new wave of next-generation eye tracking technology, including other applications such as neuroscience research and psychology."

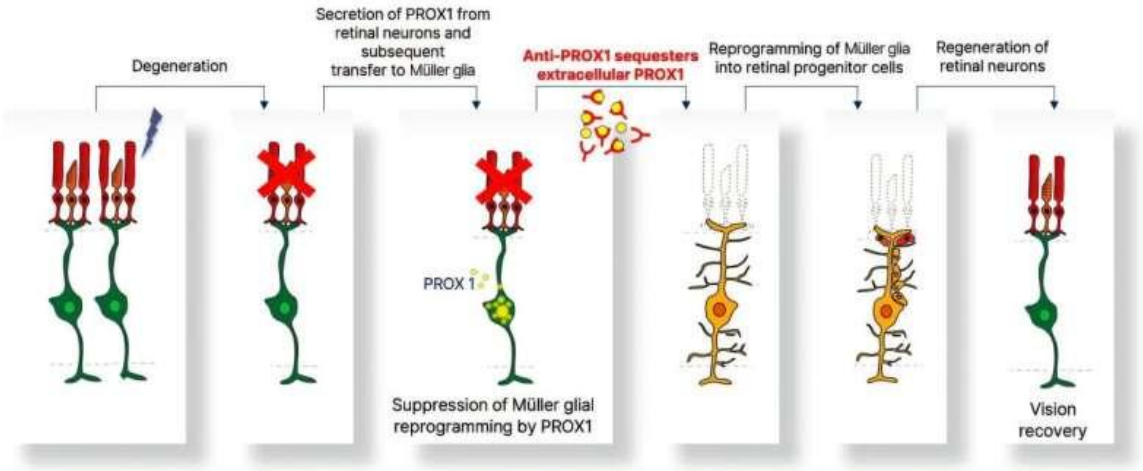
Co-authors on the paper include Oliver Cossairt, adjunct associate professor of electrical and computer engineering at Northwestern University, where Willomitzer and Wang started the project, and Tianfu Wang and Bingjie Xu, both former students at Northwestern.

More information: Accurate Eye Tracking from Dense 3D Surface Reconstructions using Single-Shot Deflectometry, *Nature Communications* (2025). DOI: 10.1038/s41467-025-56801-1
Journal information: Nature Communications

APRIL 1, 2025

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

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



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.

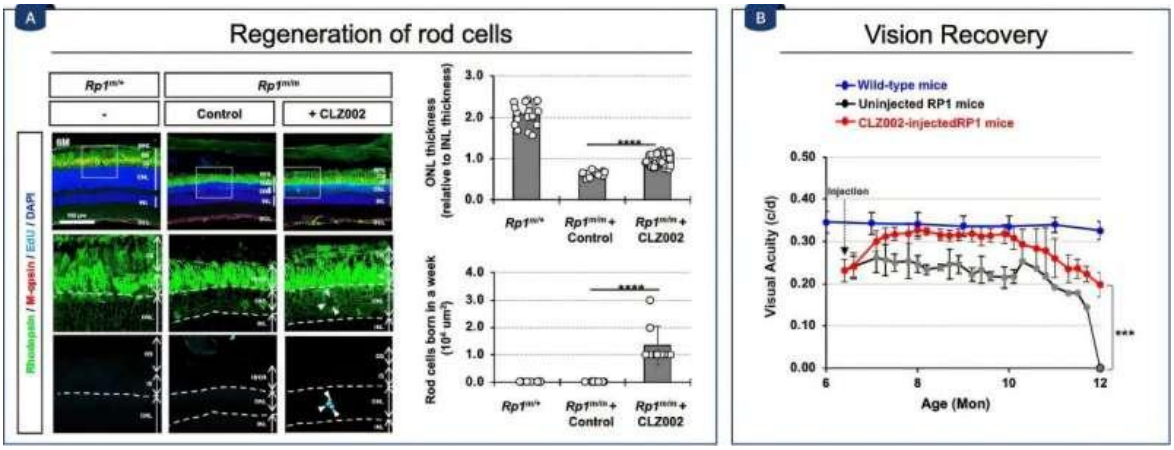
The research team successfully induced neural regeneration and vision recovery in a disease-model mouse by administering a compound that blocks the PROX1 (Prospero

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.



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

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."

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
Journal information: Nature Communications
Provided by The Korea Advanced Institute of Science and Technology (KAIST)

Action video gamers have enhanced functional and structural connectivity in the dorsal visual stream

A neuroimaging study of action video game players revealed that these individuals tend to have enhanced functional and structural connectivity in the dorsal visual stream of the brain. More specifically, they exhibited heightened functional connectivity between the left superior occipital gyrus and the left superior parietal lobule. The research was published in *Brain Sciences*.

The human brain has two distinct pathways for processing visual information: the dorsal and ventral streams. The dorsal stream, often referred to as the "where" pathway, originates in the primary visual cortex and extends toward the parietal lobe. It is primarily involved in processing the spatial location and movement of objects, helping to guide movements in relation to those objects.

In contrast, the ventral stream—known as the "what" pathway—extends from the primary visual cortex to the temporal lobe. This pathway is essential for recognizing and identifying objects, including their details and colors. Together, the dorsal and ventral streams enable the brain to integrate visual information into coherent perceptions and facilitate effective interaction with the environment by combining recognition and spatial awareness.

Study author Kyle Cahill and his colleagues hypothesized that action video game players might exhibit enhanced functional and structural connectivity within these visual streams. They reasoned that action video games often involve intensive spatial exploration, navigation, and rapid timing coordination. As a result, prolonged gameplay might lead to brain adaptations in the form of increased connectivity.

The study included 28 gamers and 19 non-gamers. Among them, 4 gamers and 12 non-gamers were female. Participants' average age ranged from 20 to 21 years. On average, gamers played action video games for five or more hours per week. The researchers focused on four types of action video games: First-Person Shooter (FPS), Real-Time Strategy (RTS), Multiplayer Online Battle Arena (MOBA), and Battle Royale (BR). Non-gamers averaged less than 30 minutes of gameplay per week across any type of video game over the previous two years.

All participants underwent magnetic resonance imaging (MRI), which focused on brain regions comprising the dorsal and ventral visual streams. The researchers used specialized software (DSI Studio 2022.08.0) to analyze structural connectivity between brain areas and to map components of both visual processing pathways.

The results showed that action video gamers exhibited enhanced functional and structural connectivity in the regions under study, particularly within the dorsal visual stream. More specifically, functional connectivity was increased between the left superior occipital gyrus and the left superior parietal lobule during a moving-dot discrimination decision-making task—a test in which participants must determine the overall direction of motion in a field of moving dots. Gamers with heightened connectivity in this region tended to have faster response times. Structural connectivity in the dorsal stream was also greater in gamers compared to non-gamers.

In the brain, structural connectivity refers to the physical network of fibers—primarily axons—that link different regions, forming a stable anatomical framework. Functional connectivity, in contrast, reflects how different brain regions interact over time, even if they are not directly connected through physical structures.

"These connectivity changes in the dorsal visual stream underpin the superior performance of action video gamers compared to nongamers in tasks requiring rapid and accurate vision-based decision-making," the study authors concluded.

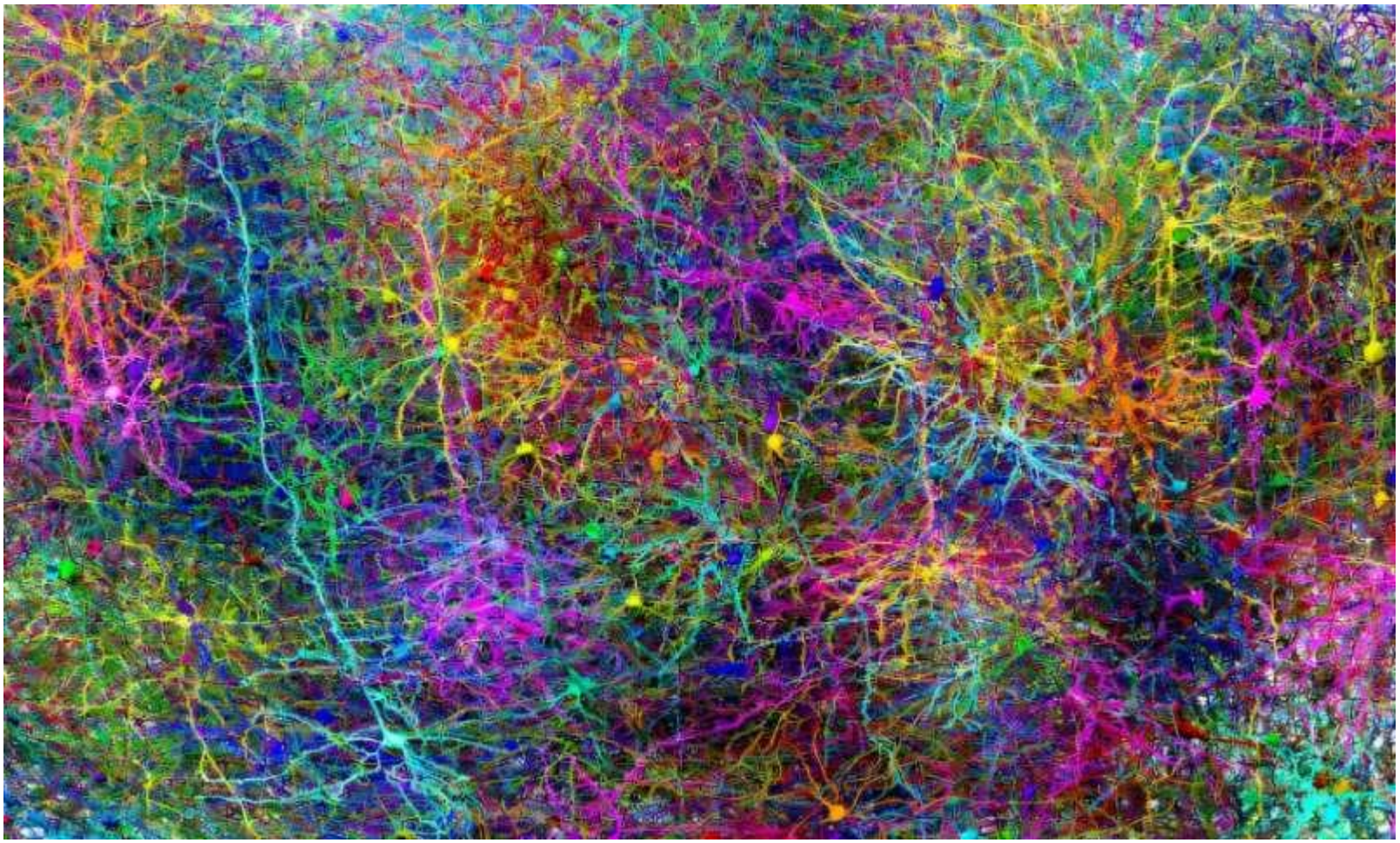
These finding provide valuable insights into how action video gaming may induce improvements in structural and functional connectivity between brain regions in visual processing pathways. However, it should be noted that the design of the study does not allow any causal inferences to be derived from the results. While it is possible that gaming induces the observed improvements in connectivity, it is also possible that people with better connectivity in these areas are the ones who become action gamers as their brain anatomy allows them to perform better than other people in such games.

The paper, "Connectivity in the Dorsal Visual Stream Is Enhanced in Action Video Game Players," was authored by Kyle Cahill, Timothy Jordan, and Mukesh Dhamala.

APRIL 9, 2025

NEURD: Proofreading the map of the brain

by Baylor College of Medicine



This image shows a subset of the more than 1,000 of the 120,000 brain cells (neuron + glia) reconstructed in the MICrONS Project. Credit: Allen Institute

From the smallest fragment of brain tissue, the intricate blueprint of the entire brain is beginning to emerge. Researchers at Baylor College of Medicine are making several time-consuming aspects of this process a lot easier with the development of a software package called NEURD short for "NEURal Decomposition." This new software increases the speed of data error detection and correction for the wiring, or "street map," of connections between cells in the brain, enabling new discoveries.

In an article published in the current edition of *Nature*, researchers describe how NEURD simplifies the process of preparing intricate datasets for a variety of downstream analyses—it proofreads, cleans up and provides an easier way to query and annotate the data with interpretable features. Furthermore, the authors show how using NEURD, this

cleaned and annotated data can be easily explored, highlighting several new findings about the brain.

"The primary goal of this collaboration has been to uncover the importance of wiring in the brain, to reveal the biological 'secret sauce' that enables the brain's extraordinary problem-solving capabilities, which remain beyond the reach of current machine learning systems," said Dr. Jacob Reimer, assistant professor of neuroscience at Baylor, a founding member of the Center for Neuroscience and AI, and senior author on the study.

MICrONS

The collaboration Reimer is referring to is The MICrONS Project, and the associated dataset of millimeter-scale electron microscopy dataset that offers an unprecedented look at the wiring and function of the mouse brain. The project spanned seven years and involved more than 150 scientists from leading institutions around the world.

The global team created the largest, most detailed wiring diagram of a mammalian brain to date from a tiny slice of mouse visual cortex, 1 cubic millimeter in size. It contains more than 523 million synapses, miles of axons and more than 200,000 cells, and what makes this wiring diagram and brain map unique, is that it also includes functional properties of neurons (their electrical signals) as well as their structural and connectivity data, providing an unprecedented look at how neurons communicate and process information as a network—providing a better picture of the hidden conversations in the brain.

The MICrONS data not only includes high-resolution anatomical images, but it also integrates live functional data collected from the same cells. A small number of previous datasets have also matched function and structure, however, on a much smaller scale.

A unique imaging process was used to capture this activity. A team of researchers that Reimer was a part of as a graduate student in the Tolias Lab at Baylor (Tolias Lab currently is with Stanford University), spent weeks recording the responses of these neurons as the mice were exposed to different visual stimuli, such as movies like "Mad Max."

Researchers at the Allen Institute for Brain Science worked on the anatomical electron microscopy data collection from the extracted tissue, and collaborators at Princeton were responsible for the reconstruction of the massive (petabyte-scale) electron microscopy anatomical volume. That meant aligning all the images and segmenting them to create a 3D image of all the neurons and associated wiring.

This approach allows scientists to study both the structure and activity of the brain in tandem, providing an unparalleled view of how neurons in the brain process sensory information. Now with his own lab at Baylor, Reimer and the Tolias lab along with other collaborating institutions, have been working to try to understand principles relating function and structure.

Enter NEURD

To further refine the data and mine it for insights, the team at Baylor along with collaborators, developed NEURD, an advanced computational tool to proofread and clean the raw data, ensuring its accuracy for scientific use.

NEURD automates the proofreading process, identifying and correcting errors in the neural networks, "cleaning" up and annotating the 3D structure. Researchers performed extensive validation of the automated proofreading approach to determine the precision and recall of error correction, ensuring that subsequent analyses can proceed with as much accuracy as possible.

"NEURD tackles the challenge of automatic neuron proofreading by breaking it down into a sequence of simpler tasks that mirror how a human typically perceives a neuron. For instance, by first identifying features like spines, we can more easily infer cell type, which in turn helps distinguish axons from dendrites—ultimately making the proofreading process more constrained and manageable," said Dr. Brendan Celii, lead author on the study and formerly with Baylor and Rice University and currently with Johns Hopkins University Applied Physics Laboratory.

Building on existing software tools that create 3D mesh images of neurons, NEURD works through automatic detection of important structures like neuron cell bodies (soma), tiny protrusions on neurons called spines, and detailed segmentation of the neuron's axon and dendritic branches. These features are designed to work across a wide range of datasets, helping researchers gather consistent data for different types of experiments.

"Proofreading is only one aspect of NEURD," Reimer said. "The other aspect is to conduct science."

As more detailed maps of neural connections are created, spanning various species and brain regions, NEURD will be crucial for advancing the understanding of neural networks. While this research is still in its early stages, the implications for human health are profound. Scientists hope to identify dysfunctions in specific neural circuits that could lead to diseases like Alzheimer's, Parkinson's or autism spectrum disorders. By better understanding these conditions at a microscopic level, treatments could be developed that target the root causes of neurological disorders.

Reimer and collaborators explain the different ways that someone can use the annotated 3D graphs produced by NEURD. For example, to categorize different classes of neurons and then calculate the probabilities of forming connections between these classes.

"We could ask questions about connectivity between classes or about different spine densities. All these features are precomputed, so you just have to think of the questions and the data is all there to be found," he said. "The scale of this research is incredibly massive, and even though it is from a mouse brain, being able to interpret this data in this way is going to give us an entirely new view of the neuronal connections in our brains."

While more work is needed and researchers are still far from mapping the human brain in full detail, the progress made is transformative.

"We're entering a new era in neuroscience, where machine learning can be integrated with biological understanding to unlock the brain's mysteries. Our hope is that NEURD will help get more researchers working to extract insights from these massive data sets," Reimer said.

More information: Celii, B. et al, NEURD offers automated proofreading and feature extraction for connectomics, *Nature* (2025). DOI: 10.1038/s41586-025-08660-5. www.nature.com/articles/s41586-025-08660-5
Journal information: Nature
Provided by Baylor College of Medicine

APRIL 8, 2025

How our unconscious memory keeps us functioning efficiently in our daily lives

by Ben Sclodnick, The Conversation

Credit: Unsplash/CC0 Public Domain

Have you ever been on a long drive and suddenly realized that you barely remember the past several minutes of driving?

Although the thought of driving without paying conscious attention to the road may be unsettling, we actually carry out complex behaviors without much thought all the time—and it's all thanks to our memory.

In its simplest form, memory does one basic job: it forms associations between things that occur together. Just as we learn to associate a name with a face, or a scent with a food, memory allows certain contexts to become associated with specific thoughts and actions.

For instance, when we learn to drive, we're taught to move our foot to the brake pedal whenever we see brake lights ahead. As we gain experience behind the wheel and these two events repeatedly occur together, we quickly reach a point where we automatically get set to press the brake pedal the moment we see brake lights—without needing to think about doing so.

Or perhaps you've noticed how fluently you can navigate through the apps and menus on your smartphone—as if your thumbs have little minds of their own—and that if someone reorganizes the apps on your home screen, this fluency can be difficult to relearn.

Each time we do something, our memory system makes connections between the behavior and the current context. With experience, behaviors that once required conscious control can be activated automatically when we encounter a familiar context.

These automatic behaviors show how memory can control our behavior without the need to consciously remember past events. Some researchers even call this form of memory "automatic control."

Because automatic memory is by nature unconscious, we often don't notice how essential it is for most of our everyday behavior. Automatic memory allows us to function efficiently.

If we couldn't rely on automatic control to trigger key actions while driving, we would be far less likely to survive those episodes of highway mind-wandering. If every thought and action required a conscious choice, something as simple as walking and talking would become an enormously demanding task.

Automatic decision-making

Driving scenarios are relatable, which makes them useful for illustrating how automatic memory works. They also show how important this form of memory is for us to function effectively.

However, once you begin looking for automatic memory elsewhere, it becomes difficult to identify behaviors that don't rely on these unconscious processes. Even our attempts to consciously control our attention may depend on automatic processes.

For example, why is it that certain things come to mind when we walk into a meeting with our boss—while very different things come to mind when you get together with an old friend? It's not as if we always make conscious decisions about what to remember in these cases.

The explanation is that these two different scenarios are each associated with different sets of past experiences. When we encounter a particular person, experiences associated specifically with them spring to mind automatically as a result of the memory associations we've formed over time.

Although automatic memory is essential to our daily functioning, it does come at a cost. For instance, we all find ourselves acting the same way over and over in familiar situations—even when those actions run contrary to the way we'd prefer to act. But the truth is, if we want to change our patterns of behavior, we need repeated opportunities to form new associations so that our automatic behaviors begin to align with our goals.

One strategy for overcoming automatic memory is to practice the behaviors you want to change in new contexts. For example, if you find that having difficult conversations with your partner always ends with you reacting negatively without meaning to, perhaps you need to try having those discussions in front of a friend or therapist.

Changing the context like this can help reduce the chance that your typical responses will be activated, making it easier to practice changing your behaviors in critical moments. For behaviors that have been built over a lifetime, there's no quick hack. Relearning takes time and effort.

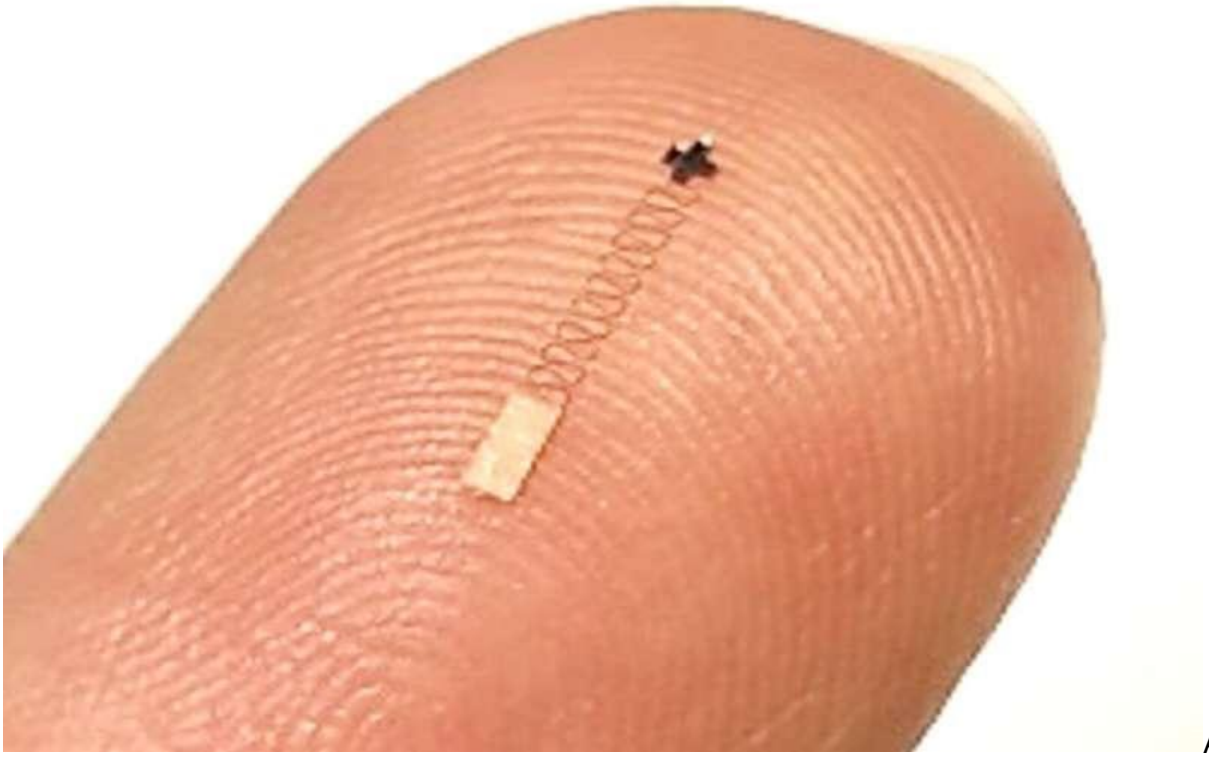
That is why, as an expert in memory and attention, I have compassion for people who struggle to change old habits. It's also why I'm downright terrified when the city adds a new stop sign to an intersection where drivers are used to having the right of way.

Provided by The Conversation

APRIL 8, 2025

Microscale brain–computer interface is small enough to be placed between hair follicles

by Bob Yirka , Medical Xpress



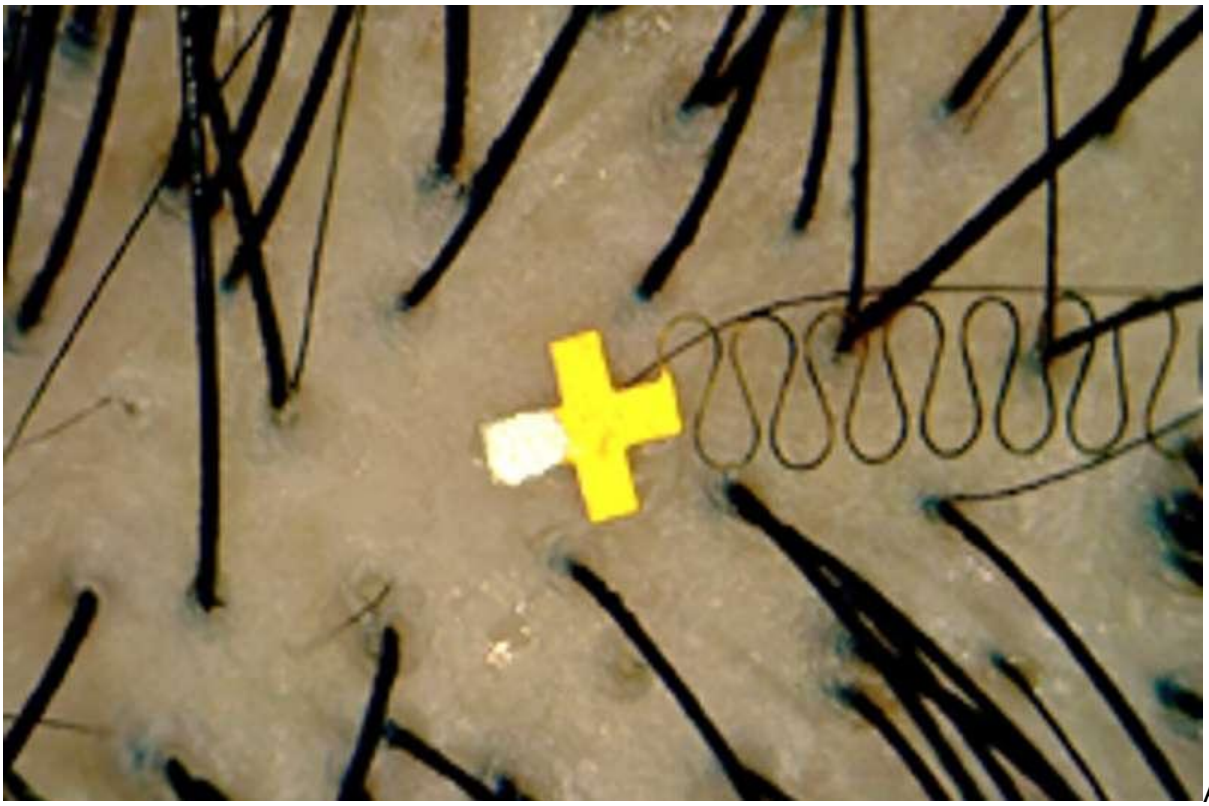
A microscale brain sensor on a finger. Credit: W. Hong Yeo

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.

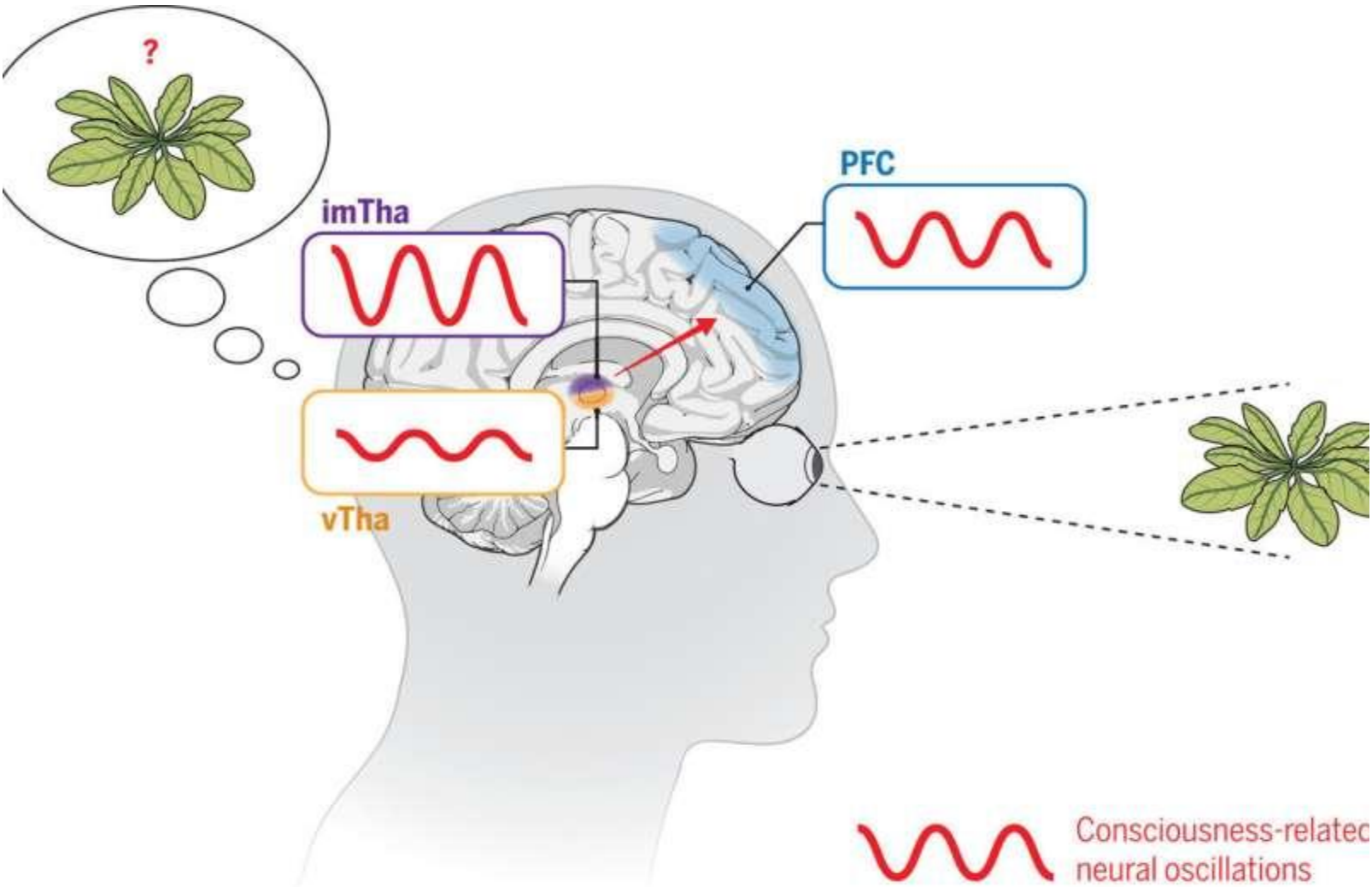
More information: Hodam Kim et al, Motion artifact–controlled micro–brain sensors between hair follicles for persistent augmented reality brain–computer

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.

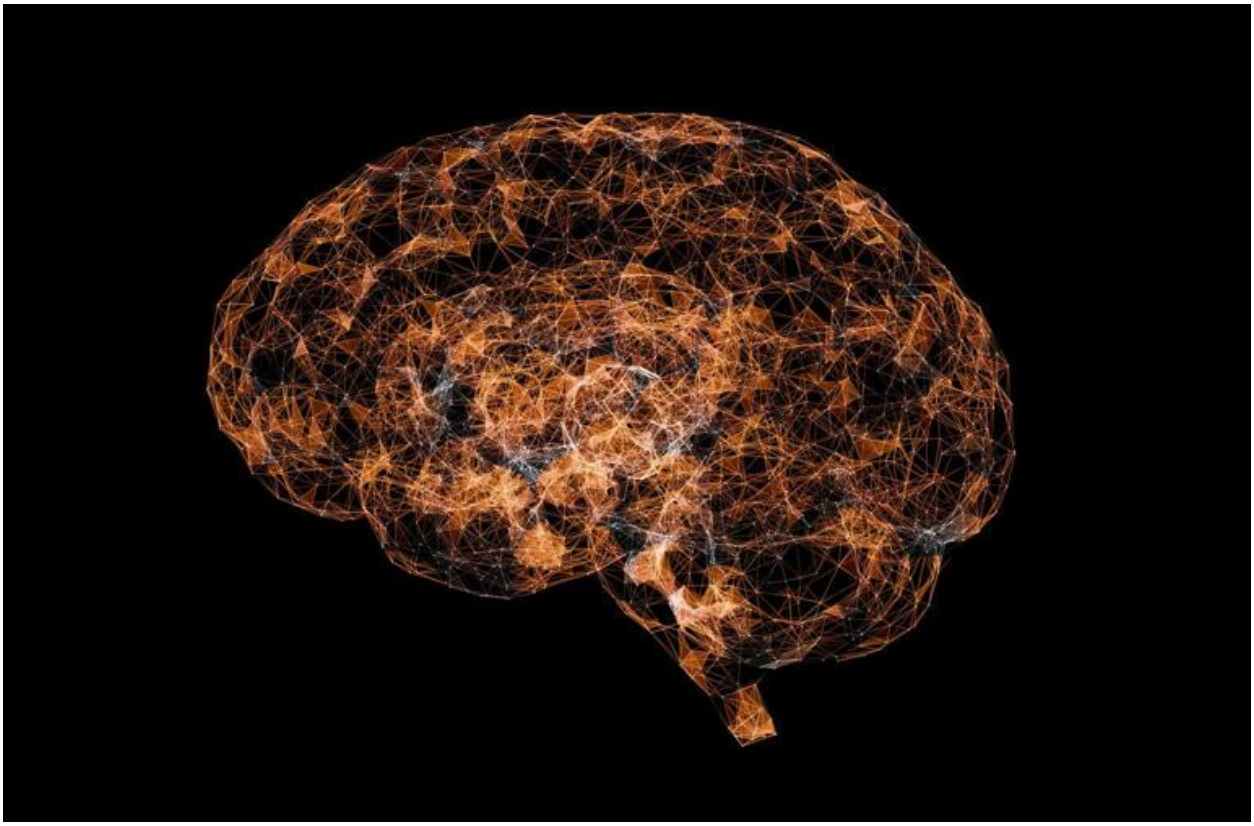
These findings add direct human evidence to support theories proposing thalamic nuclei as a gateway for conscious perception. Results challenge models that assign primary responsibility for awareness to the cortex alone. By identifying specific thalamic-cortical

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

Scientists recreate brain's pain circuit in world first



Scientists have recreated the brain circuit responsible for transmitting feelings of pain for the first time.

The breakthrough, made by a team at Stanford University in the US, could help with developing better treatments for pain disorders.

The mapping of pain pathways in a lab dish could also allow experiments and tests to be conducted on nerve circuits without causing pain to laboratory animals.

“We can now model this pathway non-invasively,” said Sergiu Pasca, a professor of psychiatry and behavioural sciences at Stanford University, who led the study.

“The [lab-built circuits] don’t ‘feel’ any pain. They transmit nervous signals that need to be further processed by other centres in our brains for us to experience the unpleasant, aversive feeling of pain.”

It is the first time that scientists have witnessed waves of electrical activity travel along the entire nervous pathway responsible for sensing pain – from the body’s skin to the brain.

They did it by creating what is referred to as a “sensory assembloid”, which is a miniaturised system made from lab-grown human cells that mimics the complex pathway used for delivering pain signals.

These assembloids now hold the potential to help test painkillers, study nerve injuries, or even create personalised treatments for patients. There is also the possibility to better understand why some people suffer from chronic pain.

“Pain is a huge health problem,” said Dr Vivianne Tawfik, an associate professor of anesthesiology, perioperative and pain medicine, who was not involved in the research.

“Some 116 million Americans – more than one in three people in the United States – are dealing with chronic pain of one kind or another.

“I can’t even tell you how sad it is to sit in front of a patient who’s suffering from chronic pain after we’ve tried everything and there’s nothing left in our arsenal.”

The research was detailed in a study, titled ‘Human assembloid model of the ascending neural sensory pathway’, published in the journal *Nature* on 9 April.

Stimulating the vagus nerve reduces susceptibility to body illusions, study finds

New research published in the journal *Psychophysiology* suggests that stimulating a nerve in the ear can make people less likely to feel that a fake hand is part of their body. This process, known as the rubber hand illusion, relies on the brain's ability to integrate different types of sensory information. The study found that people who received gentle electrical stimulation to the vagus nerve were less susceptible to this illusion, indicating they were more in touch with signals from their real body. This discovery could eventually help improve treatments for mental health conditions where bodily awareness is disrupted.

The vagus nerve plays a key role in how the body communicates with the brain. It carries signals from the heart, lungs, and other organs, helping the brain keep track of the body's internal state. Scientists have long been interested in this nerve because of its wide-reaching effects on emotion, attention, and self-awareness. In recent years, researchers have explored how stimulating this nerve might improve mental health or enhance certain brain functions.

A non-invasive method known as transcutaneous auricular vagus nerve stimulation, or taVNS, delivers mild electrical pulses to a part of the ear that connects to the vagus nerve. Past studies have shown that taVNS can improve a

person's ability to notice signals from inside the body, like their heartbeat. But researchers have not yet fully understood whether this stimulation can change how people experience their bodies more broadly—especially their sense of body ownership.

To explore this, a team of researchers asked whether taVNS could influence how people experience body ownership, using a high-tech version of the rubber hand illusion. In this illusion, a person sees a fake hand being touched in the same way and at the same time as their own hidden hand. Over time, many people begin to feel as though the fake hand is actually part of their body. This is a powerful demonstration of how the brain combines touch, sight, and body position to form a sense of physical self.

In this study, the researchers used virtual reality to recreate this illusion and included both visual-tactile feedback (a virtual brush stroking the hand) and visual-cardiac feedback (the hand flashing in time with the person's heartbeat).

"I've always been fascinated by how our sense of self emerges from the interaction between our brain and body. Body ownership—our feeling that our body belongs to us—is an essential part of self-awareness, yet it can be surprisingly malleable," explained study author Alisha Vabba, a postdoctoral researcher at the Italian Institute of Technology in the Neuroscience and Society Lab.

"Previous research suggested that interoception, or the ability to sense internal bodily signals like heartbeats, plays a role in body ownership. Since taVNS has been shown to enhance interoceptive awareness, I wanted to explore whether it could influence body ownership as well. Understanding this relationship has implications not only for neuroscience but also for clinical conditions where body awareness is disrupted."

The study included 27 healthy young adults. Each participant visited the lab twice, once receiving real vagus nerve stimulation and once receiving sham stimulation. The sessions were at least a week apart and the order was randomized. During the stimulation, electrodes were placed on the ear—either on a region connected to the vagus nerve (for real stimulation) or on the earlobe, which is not connected to the nerve (for sham).

The researchers made sure the level of stimulation was noticeable but not uncomfortable. During both sessions, participants completed a series of tasks in virtual reality designed to trigger the rubber hand illusion. In some trials, the feedback was synchronous—meaning the visual cues matched the person's heartbeat or the timing of the touch. In other trials, the feedback was asynchronous.

To measure how strongly participants experienced the illusion, the researchers used both objective and subjective measures. One was proprioceptive drift—the extent to which participants misjudged the location of their real hand, shifting toward the virtual hand. The other was a set of questions asking how strongly they felt the virtual hand belonged to them. The researchers also collected physiological data, including heart rate, heart rate variability, and skin-based nerve activity, to see how the body responded to the stimulation.

During sham stimulation, the researchers found that participants were more likely to experience the illusion when the visual and touch or heartbeat feedback was synchronized. This is consistent with earlier studies.

But during real vagus nerve stimulation, this effect disappeared. There was no difference between synchronous and asynchronous trials, suggesting that taVNS disrupted the illusion. People became less likely to feel that the fake hand was their own, regardless of whether the feedback was matched or not. This pattern was found in both the tactile and cardiac trials.

"I wasn't hugely surprised but it was interesting to note the effect we expected was observed similarly for cardiac and tactile trials," Vabba told PsyPost. "I expected to see a strong effect in the cardiac trials, as taVNS has been shown to improve interoception, making individuals more attuned to their internal bodily signals. However we saw an effect in both cardiac and tactile trials, suggesting that taVNS doesn't just enhance cardiac awareness but plays a more general role in altering multisensory integration—affecting not only interoception but also how the brain processes and combines visual, tactile, and proprioceptive signals."

The researchers also found that heart rate dropped slightly during active stimulation but not during sham, suggesting that the vagus nerve stimulation influenced the body's arousal levels. However, other physiological measures, such as variability in heart rate and skin-based nerve activity, did not show strong or consistent changes. In fact, both real and sham stimulation appeared to raise skin

nerve activity, possibly because any electrical stimulation—even if not targeting the vagus nerve—can cause a mild arousal response.

Importantly, the study did not find that a person's baseline ability to sense their own heartbeat predicted how strongly they experienced the illusion. This is worth noting because previous studies had suggested that people who are more in tune with their internal signals may be less susceptible to body illusions. Here, that link did not hold up.

"Our study shows that the vagus nerve plays a crucial role in how we integrate different sensory signals from our body," Vabba explained. "Normally, we combine visual, tactile, and proprioceptive information to create a sense of body ownership. When we applied taVNS, it altered this process—reducing susceptibility to the rubber hand illusion. This suggests that vagus nerve stimulation can shift the balance between external sensory input and internal bodily signals, making people rely more on their real body rather than external cues. This finding could have implications for understanding disorders where body perception is disrupted, such as depersonalization, certain anxiety disorders, and even chronic pain conditions."

But as with all research, there are caveats to consider. "While our study provides interesting evidence for the role of vagus nerve stimulation in body ownership, it was conducted in a relatively small sample of healthy participants," Vabba noted. "The effects of taVNS may vary between individuals, and it's unclear how long-lasting these changes are. Additionally, while we used a well-established sham control, some physiological responses (like changes in skin sympathetic nervous activity) were observed in both real and sham stimulation, suggesting that non-specific effects of electrical stimulation might also play a role."

Future studies should include a larger and more diverse group of participants and could add a no-stimulation control group to further separate the effects of the stimulation itself from the context of the experiment. In the long run, the researchers hope this work will lead to better understanding and potential therapies for disorders where the sense of bodily self is disturbed.

"A long-term goal for this line of research should be to explore how vagus nerve stimulation could be used to enhance body awareness and improve mental health conditions where interoception and self-perception are disrupted," Vabba explained. "Disorders such as anxiety, PTSD, eating disorders, and

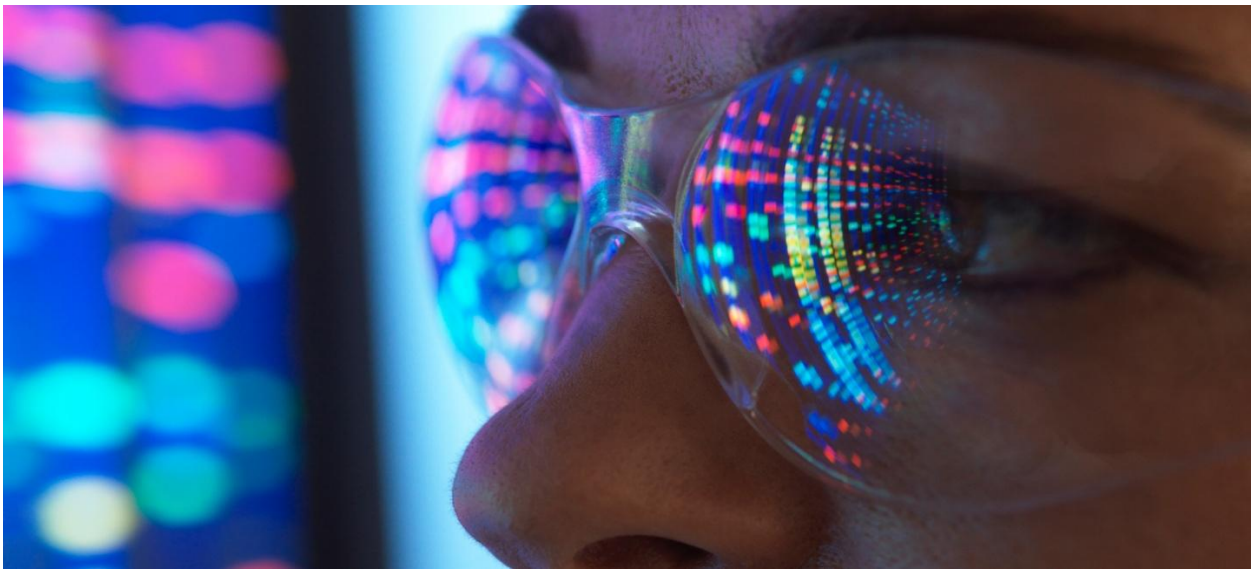
depersonalization involve altered interoception, and if taVNS can strengthen body ownership and interoceptive accuracy, it may have therapeutic potential."

The study, "The Vagus Nerve as a Gateway to Body Ownership: taVNS Reduces Susceptibility to a Virtual Version of the Cardiac and Tactile Rubber Hand Illusion," was authored by Alisha Vabba, Keisuke Suzuki, Milica Doric, Tim J. Möller, Sarah Garfinkel, and Hugo Critchley.

Holographic-inspired lenses could unlock '3rd dimension of imaging' in future VR headsets and smart glasses

published November 7, 2024

Future VR headsets could use a new type of lens inspired by holographic devices. The bilayer bifocal lens relies on external voltage to change the intensities in the foci.

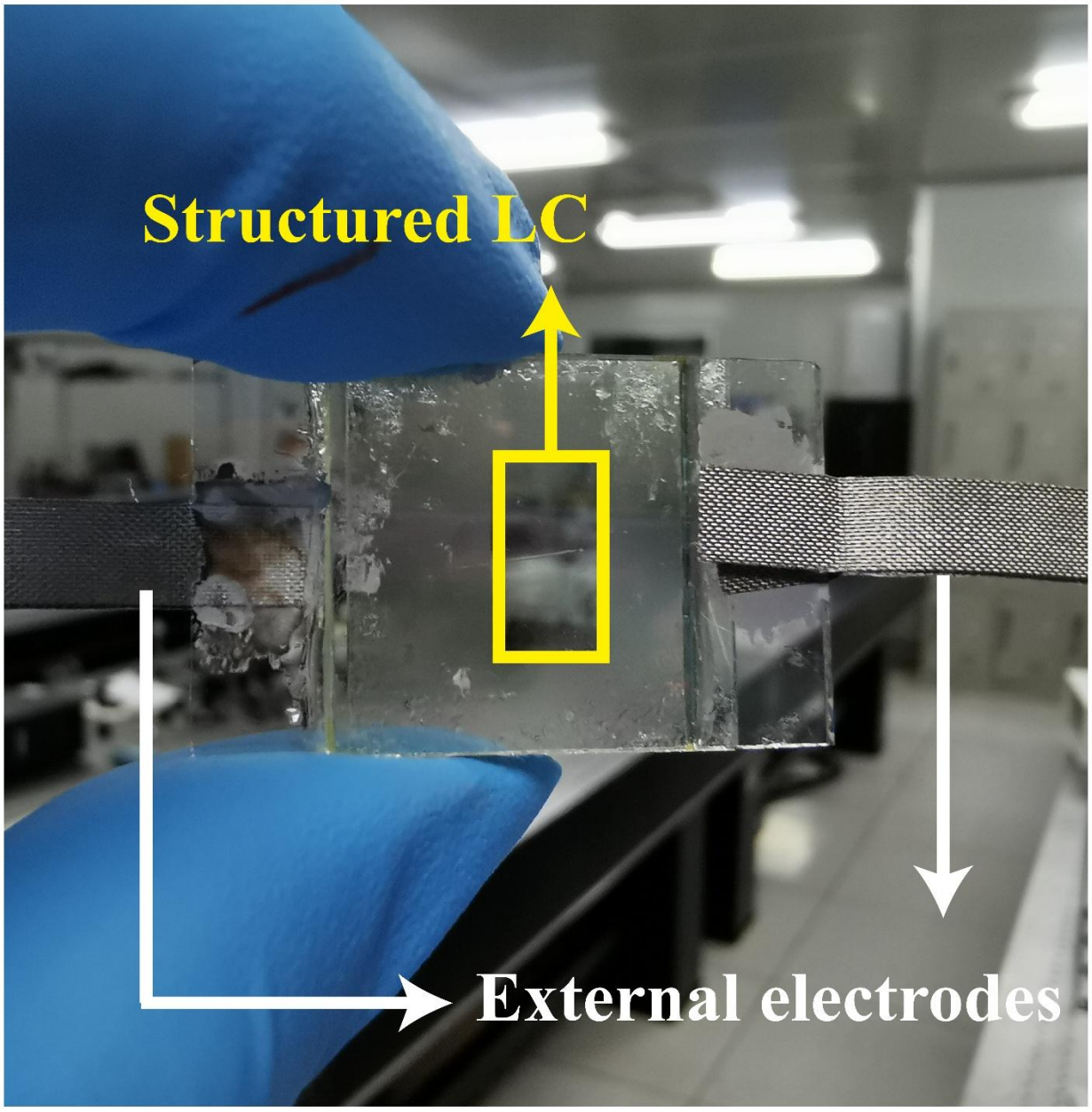


(Image credit: Andrew Brookes/Getty Images)

Future virtual reality (VR) headsets could use a new type of lens inspired by holographic devices, researchers in China say. This proposed new type of bifocal lens can switch between one focus and another at the flick of a switch, letting wearers witness intensities in the lenses change akin to a hologram.

These lenses would be made from two layers of liquid crystal structures that can switch between two foci with external voltage. The researchers described their findings in a new study published Oct. 1 in the journal Optics Letters.
The technology could be applied in imaging devices, optical computing and optical interconnectivity — in addition to future mixed-reality and VR headsets, the team said.

Specifically, they can be used for polarization imaging — often used to enhance image contrast or for edge imagining, which highlights the outline of objects or see finer details. Polarization can be referred to as the light's third dimension, with polarization cameras often detecting physical properties unseen by conventional imaging.
"We believe that the light control mechanism we created using the multilayer structure could also be used to design other optical devices, including holographic devices and beam generators, or for optical image processing," study lead author Fan Fan, professor of physics and electronics at Hunan University, said in a statement.



Researchers developed a bifocal lens based on two layers of liquid crystal (LC) structures. The intensities for the two focal lengths can be easily adjusted by applying external voltage. (Image credit: Fan Fan, Hunan University)

The team focused on creating bilayer structures, rather than single-layer structures, which most liquid-crystal devices are made from. The structures were made from a liquid crystal cell as well as a liquid crystal polymer — both of which are standard materials in the development of lenses intended for holographic imaging uses. This let researchers alter the intensity of the two foci. The development of multi-functional holographic devices was an inspiration but the technology could be used "beyond the field of holographic displays," Fan said.

Some bifocal lenses can create different focal points based on the incident light's polarization — but this new design enables the focus to switch on command, manipulating

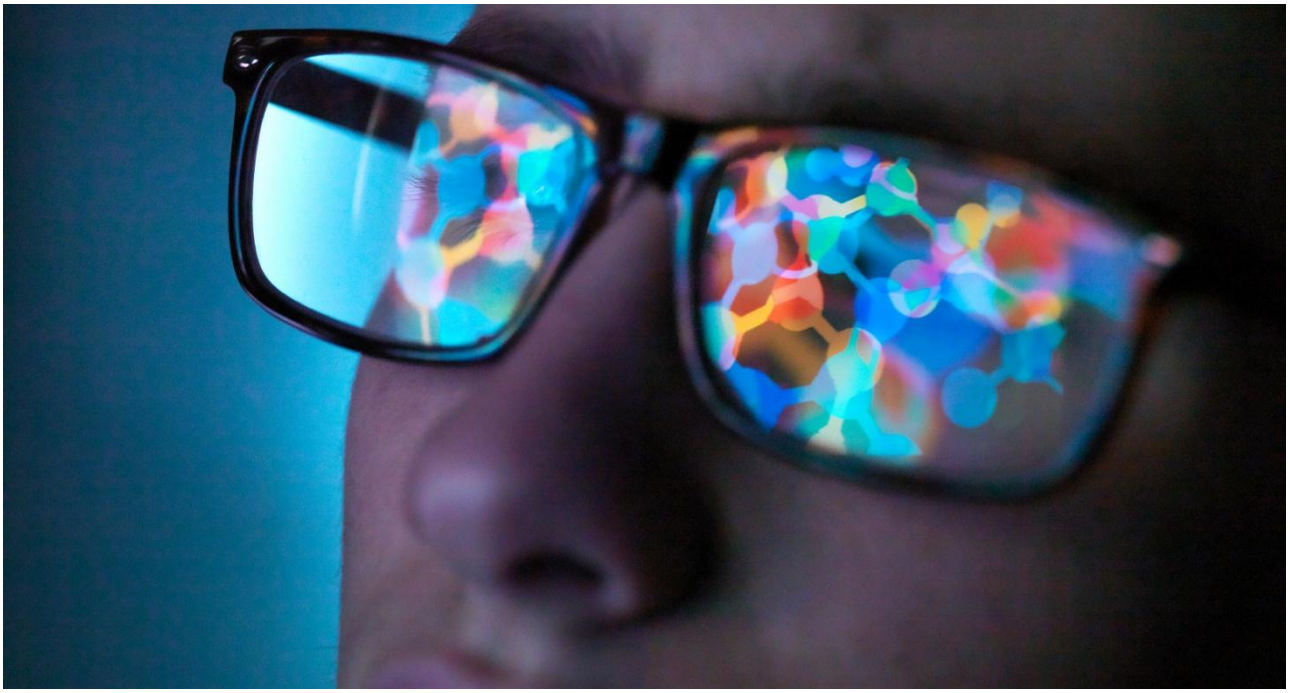
the polarization states of the output beams. The liquid crystal layer also allows the lenses to switch rapidly between focus points when voltage is applied.

The scientists are planning to use the new lenses in several kinds of multifunctional devices. For the optical components found in this technology to be more practical, however, they stressed the cost of the mass production of components would have to be lowered. If this happens, the team could design and incorporate fast and accurate layer-to-layer alignment technology, the researchers said in the statement.

New display tech paves the way for 'most realistic' holograms in regular eyeglasses

published May 28, 2024

Building on current holographic technology, a team of optical display experts have invented a way to improve 3D displays that's small enough to work in regular glasses.



Researchers are even closer to realistic holograms. (Image credit: Andrew Brookes via Getty Images)

Researchers have invented a device that’s small enough to fit in a regular pair of glasses and could solve an age-old trade-off in holographic displays — leading to the most realistic holograms ever.

Holograms are conventionally created using projecting devices called spatial light modulators (SLMs). Light is emitted through the device so that it changes the shape of the light wave at a specific distance, creating a visible surface.

But because SLMs are made from liquid crystal/silicon (LCoS) display technology, current hologram technology is suited to narrow fields of view like a flat screen or small viewing area (ie a small object). The viewer must be positioned inside a narrow viewing angle – anywhere outside it and the light diffracts too much, making the light invisible.

It's possible to widen the angle within which the image is clear, but fidelity is lost because current LCoS technology doesn't have the number of pixels available to maintain the image across a wider field. That means holograms tend to be either small and clear or large and diffuse, sometimes disappearing altogether if the viewer looks in another direction that's far enough away from the angle within which it's visible.

Felix Heide, assistant professor of computer science at Princeton and the paper's senior author, explained how important the viewing angle is. "To get a similar experience using a monitor, you would need to sit right in front of a cinema screen," he said.
The new technology, detailed in a study published April 24 in Nature Communications, could lead to the creation of more detailed holograms no matter which direction the viewer is looking in or how fast they change direction. The apparatus required to project them too is so small and light that wearers don't need tools like bulky VR headsets.

The finding would also make applications where holograms are used — such as in VR and AR displays — more widespread because the display technology can be easier to use, lighter and ultrathin. Heide mentioned examples from getting directions while driving to assisting in surgery, and even seeing instructions about how to fix a leaky pipe.

The Princeton team's key innovation was to create a second optical element that works with the SLM, filtering its output to expand the field of view while preserving the detail and stability in the hologram with a much lower decline in image quality.

Described in the paper as a small piece of frosted glass, the device is etched with a pattern that scatters the SLM's light into frequency bands not easily perceived by humans. This improves the image quality and expands the field of view.

The trade-off between image quality and field of view has been the biggest obstacle to realistic holograms, but as co-author Nathan Matsuda said: "The research brings us one step closer to resolving this challenge."

Meta just stuck its AI somewhere you didn't expect it — a pair of Ray-Ban smart glasses published May 11, 2024

Ray-Ban smart glasses will now use Meta AI virtual assistant software so that wearers can speak with their smart glasses and ask questions about what they're looking at.

Smart glasses have arguably failed to take off, but the addition of artificial intelligence (AI) could be the key to developing a truly transformational wearable technology.
In the US and Canada, Ray-Ban Meta smart glasses have received a rollout of multimodal AI technology with software called the "Meta AI virtual assistant." With multimodal AI — which means generative AI that can process queries that involve more than one medium (for example, both audio and imagery) — the device can better respond to queries based on what a wearer is looking at.

"Say you're traveling and trying to read a menu in French. Your smart glasses can use their built-in camera and Meta AI to translate the text for you, giving you the info you need without having to pull out your phone or stare at a screen," Meta representatives explained April 23 in a statement. The device first takes a photo of what a wearer is looking at, then the AI taps into cloud-based processing to serve up an answer to a query, delivered by speech, such as "what type of plant am I looking at?"

(Image credit: Meta / Ray-Ban)

Meta first explored integrating multimodal AI into the Ray-Ban Meta smart glasses in a limited release in December 2023.

Testing the AI functionality in this device, a reporter from The Verge found that it mostly responded correctly when asked to identify the model of a car. It could also describe a type of cat, for example, and its features in an image snapped via the camera. But the AI ran into trouble in accurately identifying the species of plants belonging to one reporter and struggled to correctly identify a groundhog in their neighbor's backyard.

Multimodal machinations

AI-powered virtual assistants are nothing new, with the likes of the Google Assistant, Amazon Alexa and Apple's Siri all providing smart answers to queries in natural language. But the crux of the Meta AI in the Ray-Ban smart glasses is its multimodal functionality.

The ability to fuse and process data from multiple sensor modules — for example, cameras and microphones — means a multimodal AI can generate more accurate and sophisticated outcomes versus unimodal AI systems. Google's Gemini multimodal AI model , for example,can process a photo of some cookies and respond with the recipe.

Trained on identifying patterns in different types of data inputs through multiple neutral networks — collections of machine learning algorithms arranged to mimic the human brain — multimodal AIs can process input data from text, images, audio and more.

In smart glasses, it means an AI can make sense of the world the wearer is viewing by combining sensors on the glasses with these neural networks. As a result, the system can answer more sophisticated queries and offer smarter contextual information.

But in the case of the Ray-Ban Meta device, the AI has some distance to go before it meets the AI-processing capabilities found in the latest smartphones; these benefit from more powerful chipsets and onboard sensor fusion – where data is taken from multiple sensors and processed together, for example to offer scene recognition in camera apps allowing for lighting and color balance to be intelligently adjusted, or combining data from thermometers and optical sensors in smartwatches to offer better feedback on one's workout.

Smart glasses could boost privacy by swapping cameras for this 100-year-old technology

published November 29, 2023

Researchers have built a tool called PoseSonic that can accurately track a glasses wearer's upper body movements.

Smart glasses of the future could swap out optical cameras for sonar, which uses sound to track the movements of its wearer, according to a new study. The sonar-based tech could improve accuracy and privacy, as well as make them cheaper to produce.

Scientists at Cornell University have created a technology, dubbed "PoseSonic". That combines micro sonar powered by CHIRP technology — a miniaturized version of the same technology used to map oceans or track submarines — with artificial intelligence (AI) to build an accurate echo profile image of the wearer. The micro sonar captures sound waves that are too quiet for human hearing. The tech's creators published their research 27. Sept in the journal ACM Digital Library.
"We think our technology offers tremendous potential as the future sensing solution for wearables, especially when wearables are used in everyday settings," said study co-author Cheng Zhang, an assistant professor at Cornell, and director of its Smart Computer Interfaces for Future Interactions (SciFi) Lab. "It has unique advantages over the current camera-based sensing solutions," Zhang told Live Science in an email.

Augmented reality (AR) smart glasses currently on the market, such as Ray-Ban Stories by Meta, use cameras to track the wearer, alongside wireless technologies like Bluetooth, Wi-Fi and GPS. But continuous video drains the battery quickly and may pose a privacy risk. Acoustic-based tracking, however, is cheaper, more efficient, unobtrusive and privacy-conscious, Zhang said.

PoseSonic uses microphones and speakers fitted alongside a microprocessor, Bluetooth module, battery and sensors. Researchers created a working prototype for less than $40 — and this cost can likely be reduced further if manufactured at scale. The ill-fated Google Glass, by contrast, cost $152 to make, according to IEEE, but this was ten years ago.

PoseSonic's speakers bounce sound waves that are inaudible to humans off the body and back to the microphones, which helps the microprocessor generate a profile image. This is fed into an AI model that estimates the 3D positions of nine body joints, including the shoulders, elbows, wrists, hops and the nose. The algorithm is trained using video frames for reference, which means unlike other similar wearable systems, it can work on any user without first being trained on them specifically.

Because the audio equipment uses less power than cameras, PoseSonic can run on smart glasses for more than 20 hours continuously, Zhang said, and a future version of the technology could be integrated into an AR-enabled wearable device without being uncomfortable or too bulky.

Sonar is also better for privacy than using cameras, according to the researchers, as the algorithm processes only the sound waves it produces itself to build the 3D image, instead of using other sounds or capturing images. This data can be processed locally on the wearer's smartphone, rather than sent to a public cloud server, which means it cuts the changes of data getting intercepted.

Zhang suggested two scenarios where acoustic tracking in smart glasses could be of practical use, including recognizing upper body movements in day-to-day life, such as eating, drinking or smoking, and tracking the wearer's movements while exercising. Future generations of this technology could help users monitor their behavior and allow for more detailed feedback beyond just the number of steps or the calories consumed — extending to an assessment of how the body moves during physical activity.

The Computational Limit of Life May Be So Much Higher Than We Thought, Scientists Say

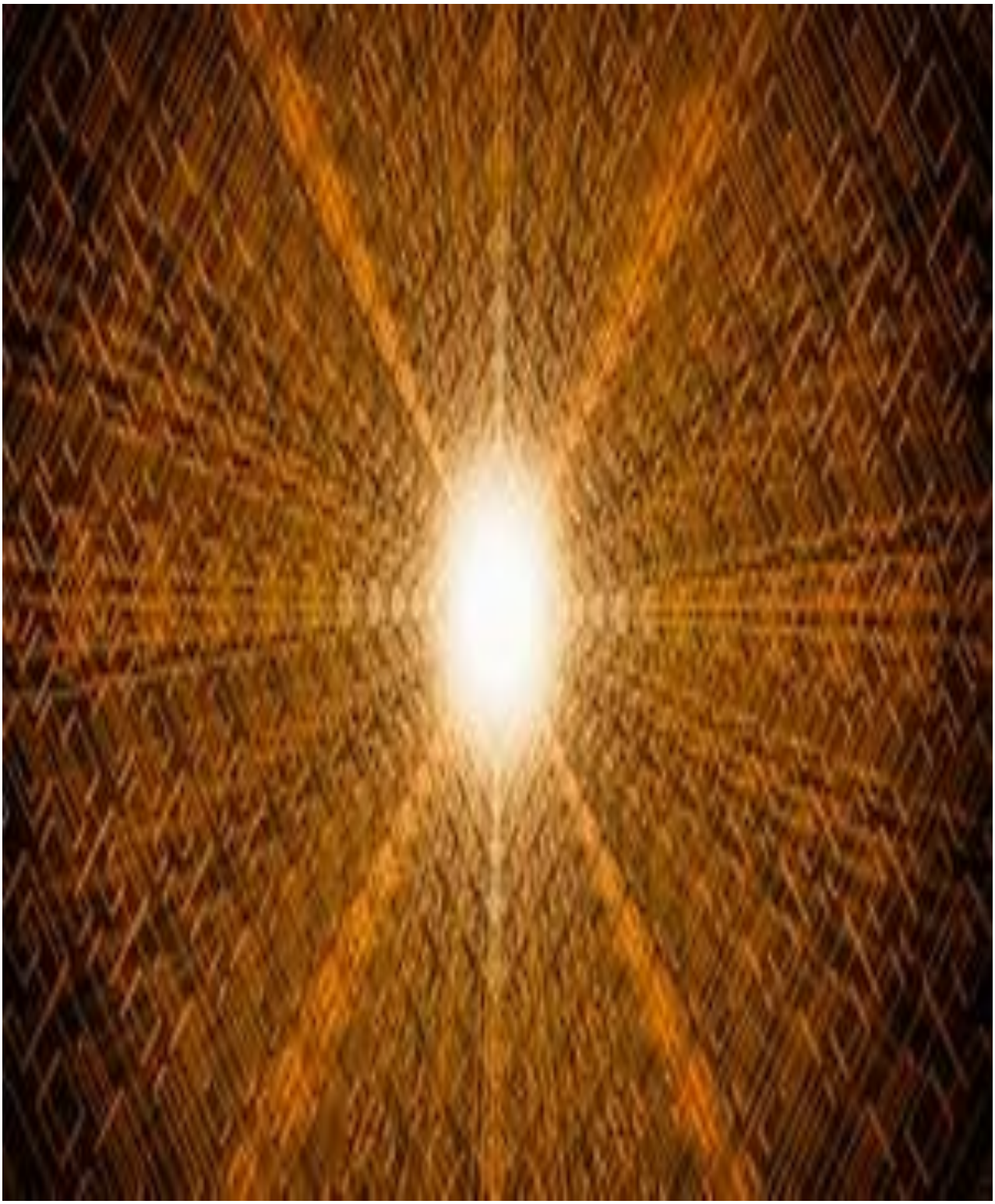
And it’s all thanks to quantum mechanics. MAY 02, 2025 9:30 AM EDT

- A new paper written by a theoretical physicist at Howard University claims that aneural eukaryotic cells could process information up to a billion times faster than typical biochemical processes.
- This idea forms from the emerging evidence that biology and quantum mechanics may not be as mutually exclusive as scientists originally thought.
- Although this idea requires rigorous experimentation to be proven, it might show that biological computation is much more powerful that even the greatest quantum computers.

What is the computational limit of biology? According to some technologists, the human brain is capable of 10^{16} computations per second, and if a **super-advanced AI** were to ever that threshold (and gain a whole host of other abilities), we'd enter hit what is known in tech circles as **the singularity**. However, a new article written by theoretical physicist Philip Kurian argues that this limit—and all other neuron-based estimations of life's computational abilities—have woefully underestimated the *true* abilities of biological brains.

Kurian includes a controversial (but increasingly influential) idea in his calculations: that quantum processes in a biological system, when taken together, far exceed the computing power of even the most advanced quantum computer. Published in the journal *Science Advances*, this article expands on QBL's **recent discovery of cytoskeleton filaments exhibiting quantum optical features** and recalculates the computational capacity of carbon-based life on Earth.

"This work connects the dots among the great pillars of twentieth century physics—thermodynamics, relativity, and quantum mechanics—for a major paradigm shift across the biological sciences, investigating the feasibility and implications of quantum information processing in wetware at ambient temperatures," Kurian **said in a press statement** ("wetware" is a term for organic material in the human body analogous to hardware in a computer). "Physicists and cosmologists should wrestle with these findings, especially as they consider the origins of life on Earth and elsewhere in the habitable universe, evolving in concert with the electromagnetic field."



Turning a Quantum Computer into a Time Crystal

Biology and **quantum mechanics** typically don't mix, and for good reason. Artificial quantum systems generally require ultracold, approaching-

absolute-zero temperatures to run, as qubits are incredibly sensitive to disturbances (this is why quantum computers also contain robust error correction measures). So, the warm and chaotic environment of, say, a human brain, is *far* from ideal for quantum processes.

However, for decades, some theories (that have slowly become *less* out there with age) have suggested that quantum processes could in fact be **occurring in the brain**. In some hypotheses, they **could even be responsible for consciousness itself**. Kurian's paper focuses on the amino acid tryptophan, which is found in many proteins and can form large networks within structures like microtubules, amyloid fibrils, cilia, and neurons. Combined with QBL's discovery last year, an idea has taken shape that aneural organisms may be able to use these quantum signals to process information.

Typically, biochemical signals involve neurons moving across cells, but in a quantum sense, tryptophan could be acting like quantum fiber optics. It would be able to perform operations in mere picoseconds, which would allow the cells to operate a billion times faster than chemical processing alone.

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

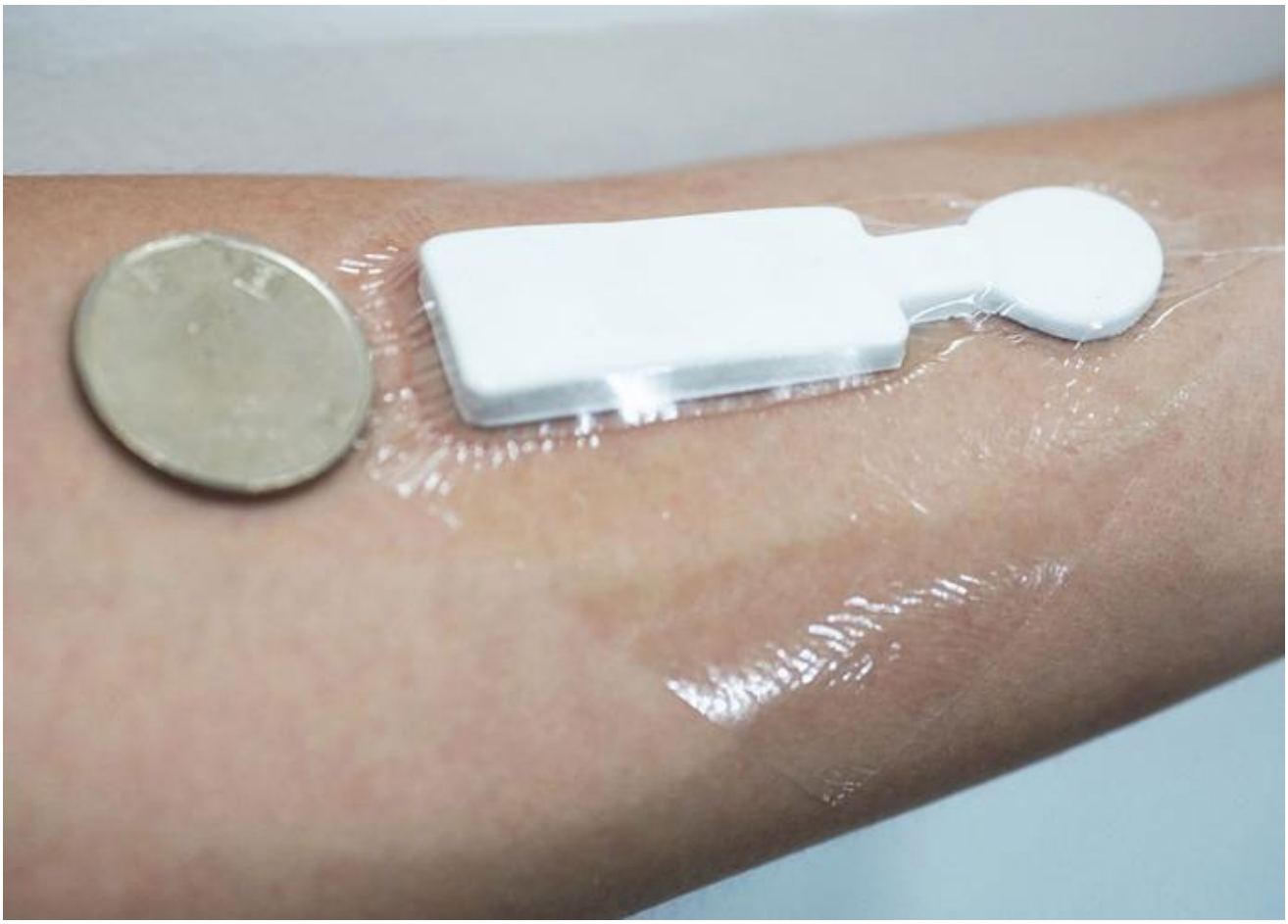
detect malfunctioning semiconductor chips through sudden heat changes.

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.

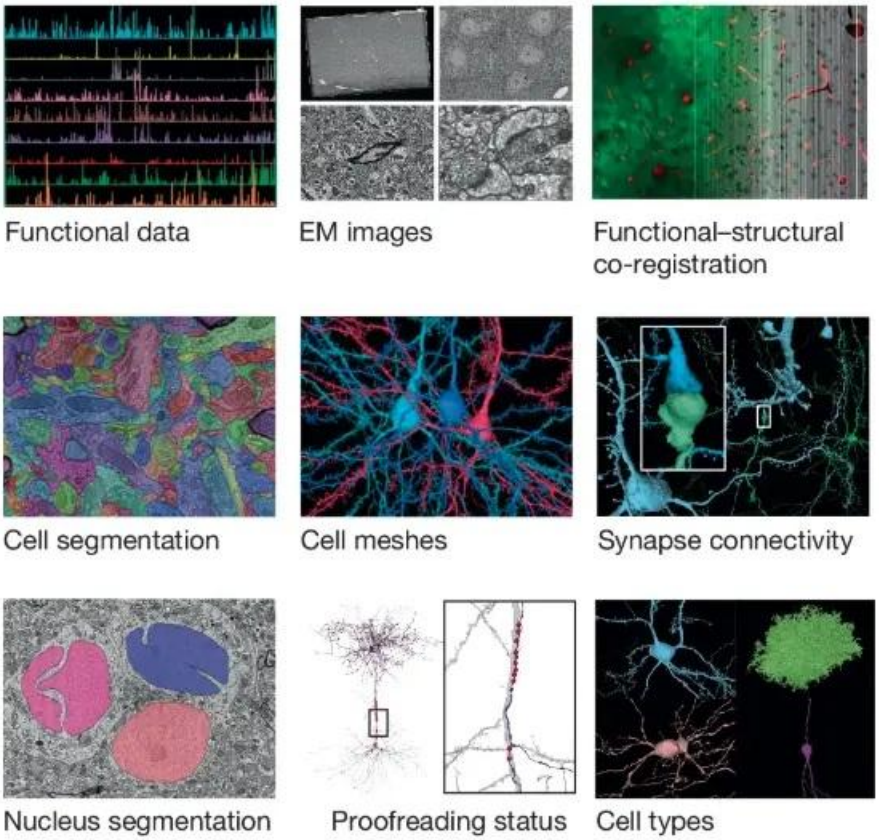
What sets the MICrONS project apart is its unprecedented integration of neuronal function and connectivity. The researchers were able to measure the responses of individual neurons to a wide range of visual stimuli, from natural scenes to artificially generated patterns. These

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.

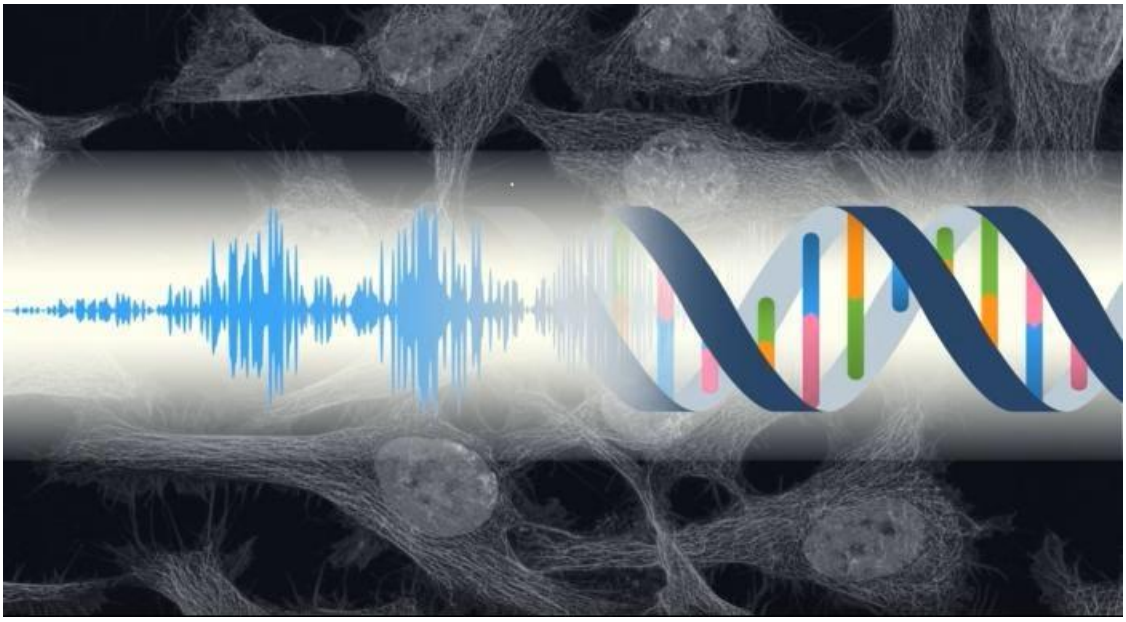
Moreover, the researchers developed new tools to facilitate large-scale proofreading and analysis of neuron reconstructions, including the ChunkedGraph system and the NEURD error correction workflow. These innovations dramatically improve the speed and accuracy of working with such massive datasets.

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."

Your cells can hear



Kyoto University researchers discover that acoustic waves can influence cellular activities, revealing new insights into mechanobiology.

From Kyoto University 17/04/25 (first released 16/04/25)

The fundamental relationship between life and sound. Credit: (KyotoU/Kumeta lab)

Kyoto, Japan — There's a sensation that you experience — near a plane taking off or a speaker bank at a concert — from a sound so total that you feel it in your very being.

When this happens, not only do your brain and ears perceive it, but your cells may also.

Technically speaking, sound is a simple phenomenon, consisting of compressional mechanical waves transmitted through substances, which exists universally in the non-equilibrated material world.

Sound is also a vital source of environmental information for living beings, while its capacity to induce physiological responses at the cell level is only just beginning to be understood.

Following on previous work from 2018, a team of researchers at Kyoto University have been inspired by research in *mechanobiology* and *body-conducted sound* — the sound environment in body tissues — indicating that acoustic pressure transmitted by sound may be sufficient to induce cellular responses.

"To investigate the effect of sound on cellular activities, we designed a system to bathe cultured cells in acoustic waves," says corresponding author Masahiro Kumeta.

The team first attached a vibration transducer upside-down on a shelf.

Then using a digital audio player connected to an amplifier, they sent sound signals through the transducer to a diaphragm attached to a cell culture dish.

This allowed the researchers to emit acoustic pressure within the range of physiological sound to cultured cells.

Following this experiment, the researchers analyzed the effect of sound on cells using RNA-sequencing, microscopy, and other methods.

Their results revealed cell-level responses to the audible range of acoustic stimulation.

In particular, the team noticed the significant effect of sound in suppressing *adipocyte differentiation*, the process by which preadipocytes transform into fat cells, unveiling the possibility of utilizing acoustics to control cell and tissue states.

“Since sound is non-material, acoustic stimulation is a tool that is non-invasive, safe, and immediate, and will likely benefit medicine and healthcare,” says Kumeta.

The research team also identified about 190 sound-sensitive genes, noted the effect of sound in controlling cell adhesion activity, and observed the subcellular mechanism through which sound signals are transmitted.

In addition to providing compelling evidence of the perception of sound at the cell level, this study also challenges the traditional concept of sound perception by living beings, which is that it is mediated by receptive organs like the brain.

It turns out that your cells respond to sounds, too.

Acoustic modulation of mechanosensitive genes and adipocyte differentiation April 2025

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Abstract

Eukaryotic cells are equipped with multiple mechanosensory systems and perceive a wide range of mechanical stimuli from the environment. However, cell-level responses to audible range of acoustic waves, which transmit feeble yet highly frequent physical perturbations, remain largely unexplored. Here, we established a direct sound emission system with a vibrational transducer, and acoustic waves at frequency 440 Hz, 14 kHz, and white noise were transmitted to the murine C2C12 myoblasts at 100 Pa intensity. After 2 and 24 h sound emission, 42 and 145 differentially expressed genes, respectively, were identified using RNA-sequencing. Both cell- and sound-related factors important for inducing gene responses were further investigated. The activation of prostaglandin-endoperoxide synthase 2/cyclooxygenase-2 (*Ptgs2/Cox-2*), a high and immediate sound-responding gene, is dependent on focal adhesion kinase activation and mediates sound-triggered gene responses by activating prostaglandin E2 synthesis. Adipocyte cells exhibited prominently high sound responses, and their differentiation was significantly suppressed by continuous or periodic acoustic stimulation. Collectively, these findings redefine acoustic waves as cellular stimulators and provide new avenues for applying acoustic techniques in biosciences.

Introduction

Eukaryotic and prokaryotic cells are equipped with various mechanosensory systems, typically comprising mechanically gated channels, membrane-linked

signalling systems, and cytoskeleton-associated molecular sensors. Forces ranging from several picoNewton to nanoNewton are directly sensed by this molecular machinery to induce adaptive cellular responses[1]. Studies focusing on cell-level responses to contact pressure, osmotic pressure, shear stress, stretch and compression forces, and substrate elasticity have revealed cellular strategies that utilise mechanical stimuli as vital external information to optimise their internal activities[1,2,3,4]. Such mechanical stimuli are essential for maintaining mechanosensitive tissues, such as bone, muscle, and adipose tissues, where they are used by cells to regulate proliferation, differentiation, metabolic activity, and cell death.

Sound, one of the most ubiquitous physical forces in nature, is a compressional mechanical wave that transmits oscillating and fluctuating pressure through substances. In a standard physiological environment, the audible range, which has a frequency range of approximately 20 Hz to 20 kHz, transmits several pascals (Pa) of pressure in air and several kPa in water. In addition to air-conducted sound sensed by the hearing system, two major types of sound transmission (bone- and soft-tissue-conducted sound) form a complicated acoustic environment inside the body[5]. Instead of the classically reported 5 N static force, which is the threshold for activating bone conduction, soft-tissue conduction was recently shown to work at a 0 N application force without direct physical contact between the sound source and body[6,7]. Research on sheep that measured the transmission of external audible sound to the foetus inside the uterus revealed approximately 5–7 decibel (dB) attenuation: 106–107 dB output of white noise (broadband noise) from a loudspeaker transmitted approximately 2 Pa pressure deep inside the body[8,9]. Meanwhile, physical contact causes a much higher body sound transmission than external audible sound. More specifically, when a mechanical force equivalent to normal human exercise was applied to an elastic object mimicking soft biological tissues, the simulated pressure was ~400 kPa (Supplementary Fig. 1). Both simulation and experimental studies have revealed the ability of hard and soft body tissues to transmit several kPa of pressure distally by several centimetres[10,11], suggesting that, under physiological conditions, the sound pressure transmitted to cells in living tissues is several kPa in magnitude. However, sound and acoustic waves have not been extensively investigated as sources of cellular stimulation. Here, in

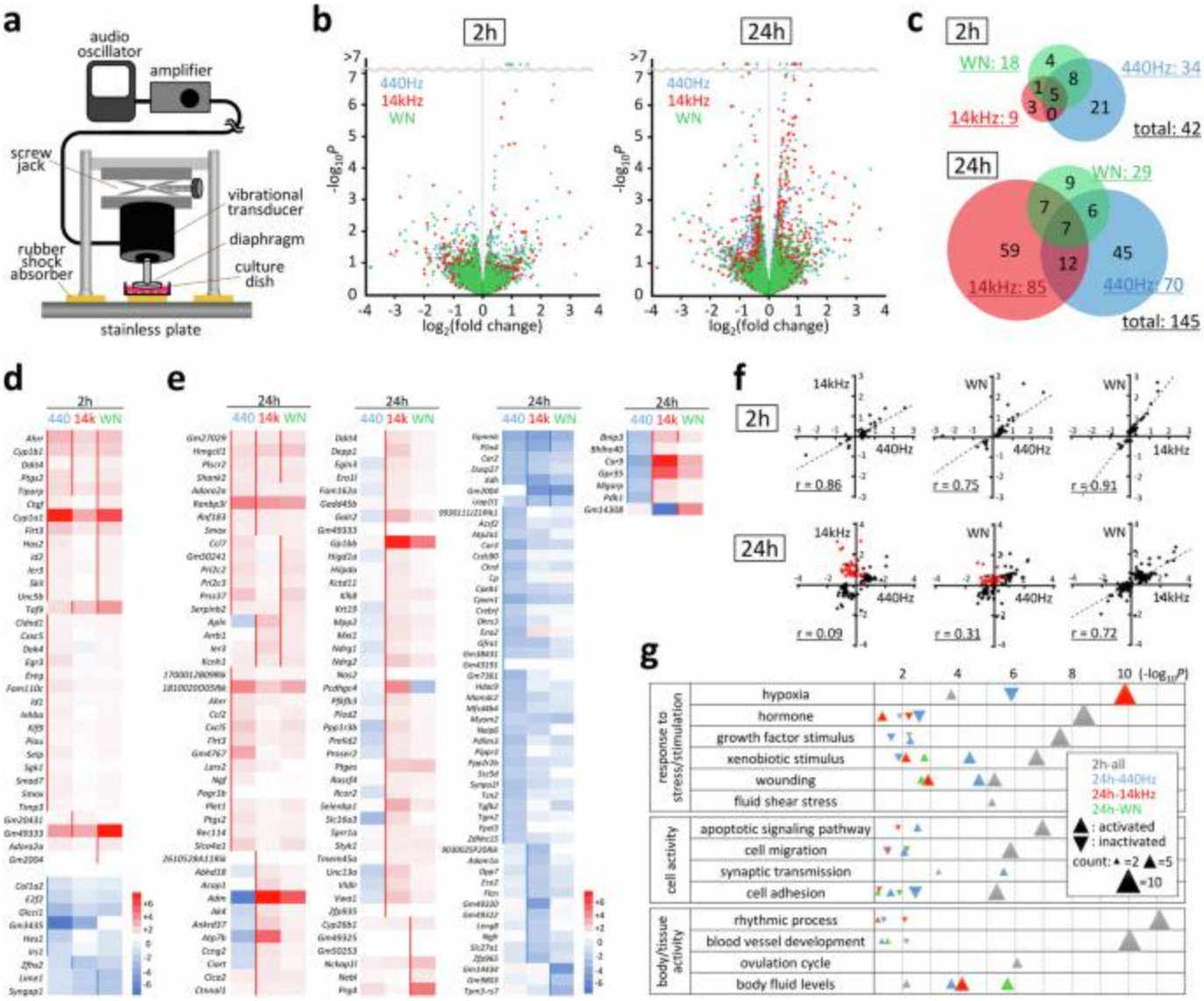
this study, we investigate how cells respond to the physiological range of acoustic irradiation that defines the biological significance of sound as a mechanical stimulation and uncover the fundamental relationships between life and sound.

Results

Identification of genes responsive to acoustic stimulation

We have previously established a sound emission system using a conventional loudspeaker that transmits several mPa of acoustic pressure, altering mechanosensitive genes[12]. In this study, we established a direct sound emission system using a vibrational transducer to generate acoustic waves directly in the culture medium (Fig. 1a, Supplementary Fig. 2a–c). A custom-made vibrating plate made of polyether ether ketone (PEEK) plastic was selected owing to its high mechanical strength, low weight, and low heat conductivity (Supplementary Fig. 2d–f). A set of sound patterns, including single-frequency sound and white noise, was generated using the NCH Tone Generator software (Supplementary Audio 1–5). The sound intensity was measured directly by recording sound in water using a hydrophone, and the pressure level was calculated. Using this system, a variety of acoustic waves can directly be transmitted to cultured cells at the maximum intensity of approximately 100 Pa, without transmitting heat from the transducer (Supplementary Fig. 2f), which is within the physiological range of sound pressure in living tissues.

Fig. 1: Identification of sound-sensitive genes.



a Schematic illustration of the direct sound emission system established in this study. The detailed setting procedure and monitoring/quantifying methods are described in Supplementary Fig. 2. **b** Volcano plots showing differentially expressed genes in C2C12 cells after 2 h and 24 h of continuous emission of 440 Hz (blue), 14 kHz (red) and white noise (green) sound at 100 Pa, identified using RNA-sequencing analyses. Samples were analysed in triplicate for each condition. **c** Venn diagrams of sound-sensitive genes identified using RNA-sequencing analyses. In total, 42 and 145 genes were identified after 2 h and 24 h of continuous emission of 440 Hz (blue), 14 kHz (red) and white noise (green) sound, respectively, at 100 Pa. **d** Heat map for 33 activated and 9 inactivated genes after 2 h of sound emission. Positive and negative fold changes are shown on a red-to-blue scale. Sidelines indicate statistical

significance ($P < 0.05$). **e** Heat map for sound-sensitive genes after 24 h of sound emission, shown in the same way as in (**d**). **f** Correlations of $\log_2$ gene response values with different sound patterns. Genes that responded oppositely to the 440 Hz and 14 kHz sound in 24 h are indicated in red. **g** Biological activities significantly affected by sound emission, revealed by gene annotation analysis performed using Metascape[13]. Pathways with high statistical significance ($-\log_{10}P > 5$) are listed.

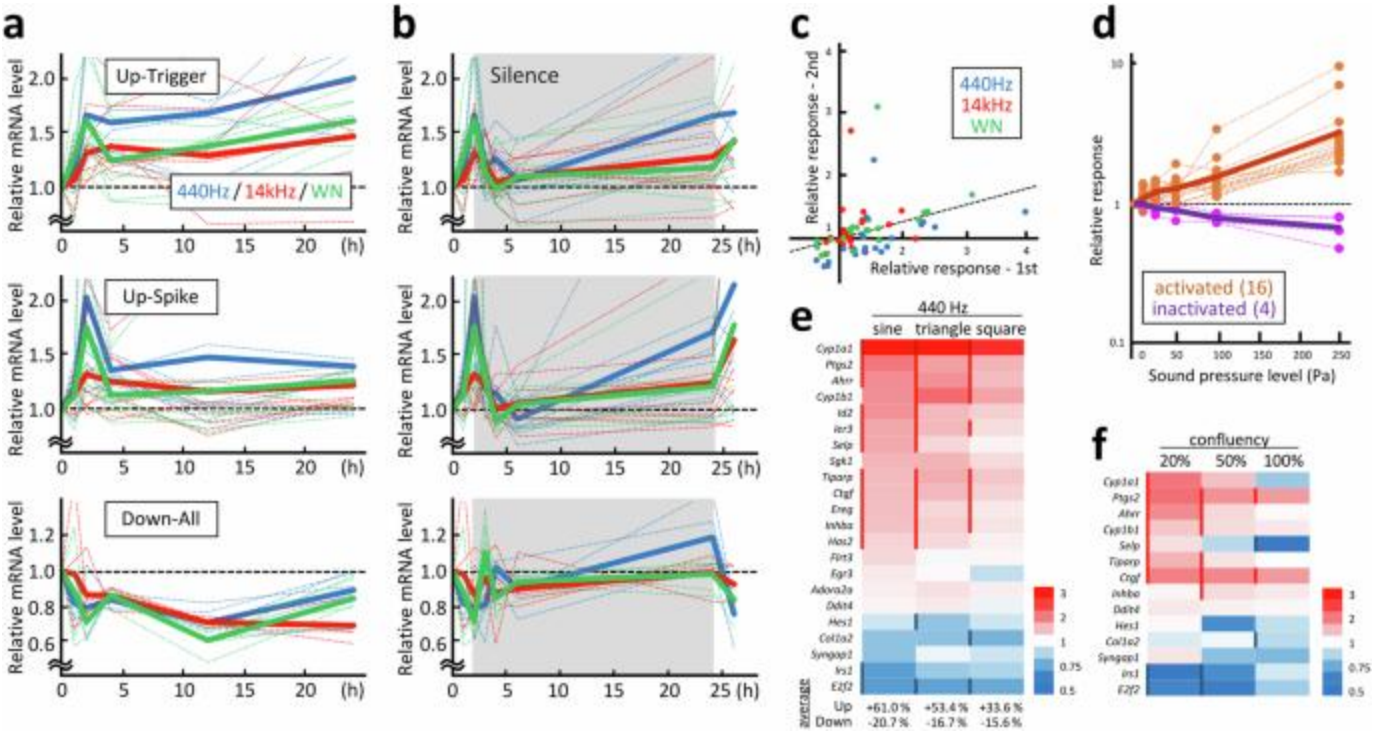
The murine C2C12 myoblast cell line was selected to investigate acoustic responses since it showed significant gene responses in our previous study[12]. The cells were cultured in plastic dishes at approximately 50% confluence and subjected to acoustic stimulation. Single-frequency sine-wave sounds at 440 Hz and 14 kHz were selected as representatives of low and high audible frequencies, respectively, while white noise was selected as a broadband source with uniform frequency characteristics. After 2 h and 24 h of continuous sound emission at 100 Pa, total RNA was extracted and subjected to gene expression profiling using RNA-sequencing. In total, 42 early- and 145 late-response genes were identified as sound-sensitive after 2 h and 24 h of stimulation, respectively (Fig. 1b, c). The 42 early-response genes included 33 upregulated and 9 downregulated genes. Among these, five exhibited consistent upregulation in all three sound patterns. The 145 late-response genes included 86 upregulated, 52 downregulated, and 7 dual-response genes (i.e., upregulated by one sound pattern and downregulated by the other). The heat map shows that the early-response genes responded similarly to the three sound patterns (Fig. 1d). However, several characteristically unique responses to the different sound patterns were observed after 24 h (Fig. 1e). In particular, a set of genes significantly upregulated by the 14 kHz sound was downregulated by the 440 Hz sound (indicated in red in Fig. 1f). This may be primarily due to the different fluid actions of the culture medium; the 440 Hz vibration caused convective mixing of the medium, while the 14 kHz high-frequency vibration induced much less flow, because the amplitude of particle displacement of sine wave is inversely proportional to the frequency. In our experimental system, a diaphragm covering 80% of the dish area was attached to the culture medium to efficiently generate acoustic waves. Taken together

with the fluid action, 14 kHz stimulation generated a certain extent of hypoxia in the culture medium as many of the 14 kHz responsive genes were found to be involved in the cellular response to hypoxia (Supplementary Fig. 3a). Gene annotation analysis using Metascape[13] revealed various molecular, cellular, and body/tissue-level activities affected by acoustic stimulation (Fig. 1g). In addition to the known mechanosensitive activities, such as fluid shear stress response, cell migration, cell adhesion, and blood vessel development, various pathways and processes were identified including apoptosis, synaptic transmission, and rhythmic process that may be unique responses to acoustic stimulation.

Cellular and acoustic factors involved in the response

The responses of the sound-sensitive genes at different time points and for variable sound patterns were further analysed. A set of early-response genes was selected for further analyses using quantitative polymerase chain reaction (PCR). Gene responses were classified into two patterns when the cells were exposed to continuous 100 Pa acoustic stimulation: triggered-type genes maintained altered mRNA levels for hours, whereas spiked-type genes responded transiently and returned to their basal expression levels (Fig. 2a). The upregulated genes were separated into two types, whereas the downregulated genes were mostly found to be of the triggered type. A significant overlap was not observed between the functions of the triggered- and spiked-type genes (Supplementary Fig. 3b). Gene responses to growth factors are known to be transient, whereas those to hormones and apoptotic stimulation are slower and persistent[14,15,16]. This highlighted the dual effects of acoustic stimulation on both signal transduction events. Most gene activity returned to basal levels after 2 h when the cells were exposed to sound for only 2 h, followed by incubation in a silent environment (Fig. 2b). Meanwhile, most genes responded repeatedly when the sound was re-emitted after 24 h. The relative intensity of the primary and secondary responses was 1:0.26, demonstrating the repetitive nature of the sound-induced gene responses (Fig. 2c).

Fig. 2: Cellular and acoustic factors affecting gene responses.



a Time-course patterns of sound-sensitive gene responses analysed using quantitative PCR. Based on the response pattern to 440 Hz acoustic stimulation, genes were grouped into upregulated in the triggered pattern (8 genes), upregulated in the spiked pattern (9 genes), and downregulated (5 genes). Dotted lines indicate each gene, and thick lines indicate the averaged responses for continuous emission of 440 Hz (blue), 14 kHz (red) and white noise (green) sound. **b** Gene response patterns for silence and re-emission sound. After 2 h of emission, the sound was stopped for 24 h (highlighted in grey), and the same sound was re-emitted for 2 h. Grouping and data representation are the same as in (**a**). **c** Comparison of the responses for the 1st and 2nd sound emissions presented in (**b**). Relative responses for the 1st stimulation (0−2 h) and 2nd stimulation (24−26 h) are shown on the X- and Y-axes, respectively. The linearly approximated line indicates a 2nd-to-1st response rate of 0.26 on average. **d** Gene responses at different sound pressure levels. The 440 Hz sound was emitted at 10, 25, 50, 100, and 250 Pa for 2 h. Dotted lines indicate activated (16 genes, orange) and inactivated (4 genes, purple) genes, and thick lines indicate the averaged responses. **e** Gene responses to different waveforms. Sine-, triangle-, and square-waved 440 Hz sound was emitted at 100 Pa for 2 h. The relative gene response is shown on a red-to-blue scale, and the sidelines indicate statistical significance ($P < 0.05$).

The average values for the upregulated and downregulated genes are shown below. **f** Effect of cell confluence on sound-sensitive gene responses. The relative response is shown on a red-to-blue scale, and the sidelines indicate statistical significance ($P < 0.05$).

Frequency, intensity, and waveform are the three major factors that determine the properties of sound. Proportional responses were observed for sound-activated and inactivated genes after applying 440 Hz sound with 10–250 Pa intensity (Fig. 2d). Considering that the sound energy quantity proportionally correlates to the square of the sound pressure and amplitude, these gene responses were expected to occur owing to a mechanical sensing system, rather than the energy conversion process. The effect of different waveforms was also assessed using 440 Hz triangle and square waves, which are enriched in high-frequency components in addition to the basic 440 Hz frequency (Supplementary Fig. 4). Similar gene response patterns were observed 2 h after sound emission when the sounds were emitted at an intensity of 100 Pa (Fig. 2e). The sine wave was slightly more efficient than the other waveforms, as revealed by the quantitative comparison of the averaged gene responses.

Cell density is an important cellular factor in this response. Indeed, several gene responses were abolished or even reversed at high or low cell densities when cells of different densities were prepared (Fig. 2f). Considering the cellular and acoustic factors affecting gene responses, we focused on prostaglandin-endoperoxide synthase 2 (*Ptgs2*, also known as cyclooxygenase-2 [*Cox-2*]) and connective tissue growth factor (*Ctgf*, also known as cellular communication network factor 2 [*Ccn2*]) as marker genes for sound-triggered gene responses, as they exhibited high and stable responses under different cellular and acoustic conditions.

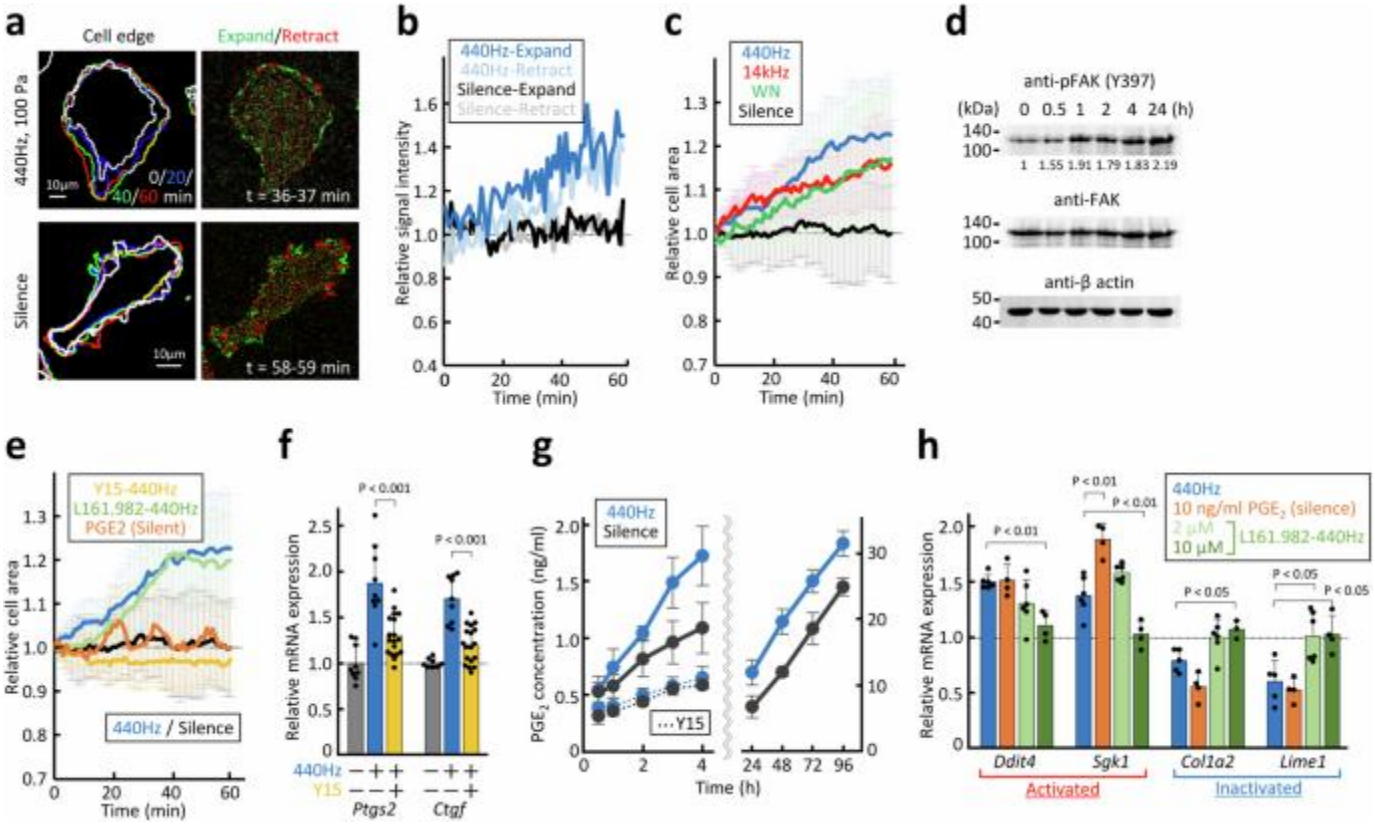
We have previously shown that *Ptgs2* and *Ctgf* are suppressed by the indirect emission of acoustic waves by a loudspeaker system[12]. These genes are mechanosensitive and show opposite responses to opposing forces, such as stretching and compression[17,18]. In contrast to the simple direct sound emission system used in this study, the indirect loudspeaker system produced

a complicated acoustic field, as the sound generated in the air was not only transmitted to the medium but also vibrated the dish or baseplate. To assess the sound transmission modes of the loudspeaker system, a sound-field simulation was performed with different combinations of water, dish, and baseplate. Comparison of the pressures observed at the detection point revealed that among the total sound reaching the cells, the sound transmitted from the air to the medium only accounted for ~40% (Supplementary Fig. 5). Therefore, the sound transmitted by a dish or baseplate is suggested to act as a suppressor of sound-responsive genes. To further test this postulation, the sound was emitted by a vibrational transducer without fixing the dish, allowing free vibrations of the dish. Under these conditions, the responses of *Ptgs2* were significantly reduced, supporting our interpretation that indirectly transmitted sound elicited opposing effects to directly generated sound on sound-responsive genes (Supplementary Fig. 6).

Mechanisms involved in perception and transmission of acoustic stimulation

To understand the signal transduction mechanisms leading to gene responses, the cellular effects of acoustic stimulation were investigated. The vibrational transducer was mounted on a microscope stage with a heating system (Supplementary Fig. 7a). As the sound emission (especially at low frequencies) significantly disturbed the image quality of the laser-scanning microscope, several averaging processes were applied (Supplementary Fig. 7b). C2C12 cells expressing EGFP-fused Lifeact were subjected to 440 Hz sine-wave, 14 kHz sine-wave, or white noise emitted at 100 Pa. Time-lapse observations and tracing of the cell area revealed expansion of the cell edge in response to acoustic stimulation (Fig. 3a). In contrast to the filopodia-dominant cell edge fluctuation of the silent cells, the sound-irradiated cells exhibited a clear expansion with lamellipodial smooth edges. Quantification of the cell expansion and retracttion revealed that both activities were activated by sound stimulation, suggesting the involvement of cytoskeletal remodelling factors related to cell migration and adhesion (Fig. 3b); this agrees with the results of the gene annotation analysis (Fig. 1g). All three sound patterns acted similarly to increase the cell adhesion area by 15–20% in 1 h (Fig. 3c).

Fig. 3: Pathways involved in the perception and transmission of acoustic stimulation.



a Live observation of C2C12 cells expressing EGFP-Lifeact under acoustic stimulation with 440 Hz sine-wave sound at 100 Pa. Image processing procedures are described in Supplementary Fig. 7. Cell edges at time 0, 20, 40, and 60 min are overlaid in white, blue, green, and red, respectively. Expanded and retracted areas in 1 min are shown in green and red, respectively. Results are shown in the movies in Supplementary Movies 1–4. **b** Time-course changes in relative intensity of signals of expanding/retracting areas under 440 Hz stimulation (blue/light blue) or silence (black/grey). **c** Time-course changes in relative cell area at 440 Hz (blue), 14 kHz (red), and white noise (green) stimulation at 100 Pa or under silence (black). $n \geq 5$ for each condition, and vertical bars indicate ± SD. **d** Western blot analysis of C2C12 whole-cell lysate taken at the indicated time point after starting 440 Hz continuous acoustic stimulation at 100 Pa. After blotting with an anti-phospho Y397 FAK antibody, the membrane was stripped and reblotted with an anti-FAK antibody. Anti-β actin blotting was performed as a loading control. Normalised signal intensities of phosphorylated FAK relative to those of total FAK are indicated. Unedited original blot images are shown in Supplementary

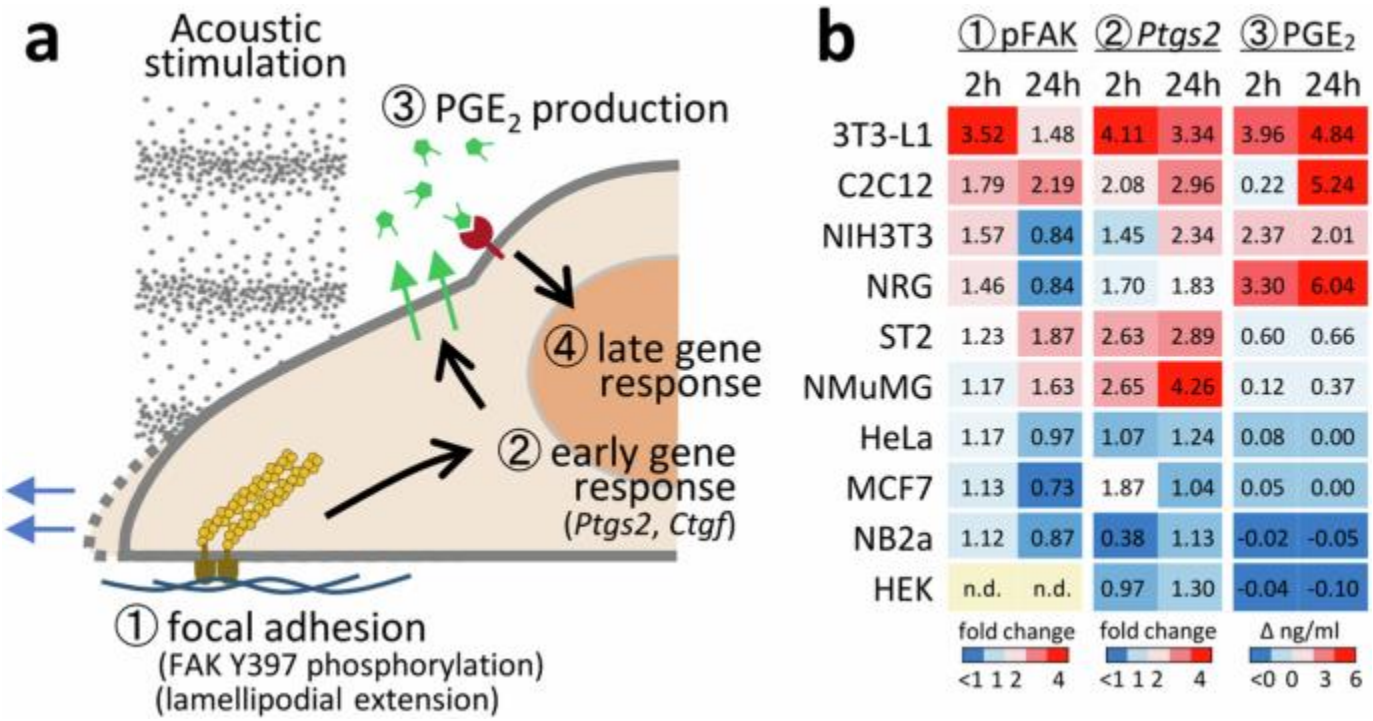
Fig. 11. **e** Time-course changes in the relative cell area under 440 Hz (blue) sound, silence (black), 440 Hz sound with 2 μM Y15 (yellow) and 10 μM L161.982 (light green), and silence with 10 ng/ml PGE_2 (orange). $n \geq 5$ for each condition, and vertical bars indicate ± SD. **f** Expression levels of *Ptgs2* and *Ctgf* after 2 h emission of 440 Hz sound at 100 Pa in the presence (yellow) or absence (blue) of 2 μM Y15 relative to those of the silent condition (grey). Bars represent +SD from 3 biological replicates of ≥3 independent experiments, and statistical significance was evaluated using one-way ANOVA followed by Tukey's HSD test. **g** Amount of PGE_2 released into the culture medium was quantified using a chemiluminescence assay under 440 Hz continuous stimulation at 100 Pa (blue) or silence (grey) at different time points. Dashed line indicates results in the presence of 2 μM Y15, added 1 h before starting the sound stimulation. Bars represent ± SD from $n \geq 3$. **h** Responses of four sound-sensitive genes in the presence of 10 ng/ml PGE_2 (orange) or 2/10 μM L161.982 with 440 Hz stimulation (green). Bars represent +SD from three biological replicates of two independent experiments, and statistical significance compared with 440 Hz sound alone (blue) was evaluated using one-way ANOVA followed by Tukey's HSD test.

Focal adhesion is a major cell adhesion structure connecting the cytoskeleton to the extracellular matrix and functions as a sensor of mechanical stimuli, such as physical forces and matrix rigidity[19]. Focal adhesion kinase (FAK) plays an essential role in mechanotransduction at focal adhesions by organising cytoskeletal dynamics and regulating adaptive gene expression and cell adhesion/migration activities[20,21,22]. Phosphorylation of Y397 of FAK stabilises focal adhesions and promotes the expansion of the lamellipodial cell edge[23]. Western blot analysis revealed a time-dependent increase in Y397 phosphorylation following acoustic stimulation (Fig. 3d). Cell expansion in response to acoustic stimulation was abolished when the cellular response was observed in the presence of Y15—a specific inhibitor of FAK Y397 phosphorylation (Fig. 3e). Under this condition, the responses of *Ptgs2* and *Ctgf* were abrogated, demonstrating the upstream role of FAK phosphorylation in these gene responses (Fig. 3f).

The downstream events were also investigated. *Ptgs2* encodes a key enzyme that regulates the biogenesis of prostaglandin E2 (PGE_2) and is involved in the adaptive regulation of PGE_2 production. The amount of PGE_2 released in the medium was 1.2–1.8 times higher for 4 days when 440 Hz sound was continuously emitted than that in the silent environment (Fig. 3g). This effect was dependent on the acoustic response via FAK signalling, as Y15 abolished the effect of sound. Several sound-responsive genes (Fig. 1d, e) were identified as responsive to increased PGE_2 production. Gene responses similar to those in acoustic stimulation were observed without sound emission when comparable amounts of PGE_2 were added to the medium (Fig. 3h). L161.982—an inhibitor of the major PGE_2 receptor, EP4—, cancelled the effect of sound on these genes, demonstrating that *Ptgs2* activity is a trigger for a set of sound-responsive genes. Furthermore, L161.982 treatment did not affect cell morphological responses to sound, whereas adding PGE_2 alone to the medium did not induce cell adhesion (Fig. 3e).

Taken together, the acoustic signal transduction pathway is initiated at focal adhesions, induces *Ptgs2* response via FAK phosphorylation, and increases PGE_2 activity against the EP4 receptor, activating a gene set (Fig. 4a). Consequently, the cells reinforced focal adhesions and expanded their adhesion areas.

Fig. 4: Pathway model and cell-type specificity of acoustic signal transduction.



a Model of the acoustic signal transduction pathway revealed in this study. **b** Cell-type specific response to acoustic stimulation. In addition to C2C12 myoblast derived from muscle tissue, 3T3-L1 (fibroblast, embryo), HEK (epithelial, kidney), HeLa (epithelial, cervix), MCF7 (epithelial, breast), NB2a (neuroblast, neuroblastoma), NIH3T3 (fibroblast, embryo), NMuMG (epithelial, breast), NRG (fibroblast, bone marrow), ST2 (fibroblast, bone marrow) cells were subjected to 440 Hz acoustic stimulation at 100 Pa intensity for 2 and 24 h. Phosphorylation states of FAK Y397 were analysed by quantifying pFAK/FAK signal intensities of Western blotting using anti-FAK and anti-pFAK antibodies, and the effect of acoustic stimulation was evaluated over silent condition. Blue-to-red indicates fold change from <1 to 4. Anti-pFAK signal was not detected for the HEK cell sample (n.d.). Expression of *Ptgs2* was analysed by quantitative PCR and evaluated over silent condition. Blue-to-red indicates fold change from <1 to 4. Concentration of PGE_2 in the culture medium was measured by PGE_2 CLIA kit, and the increase by the acoustic stimulation (Δng/ml) was shown in blue-to-red indicating <0 to 6 ng/ml increase of PGE_2. Detailed data were presented in Supplementary Fig. 8.

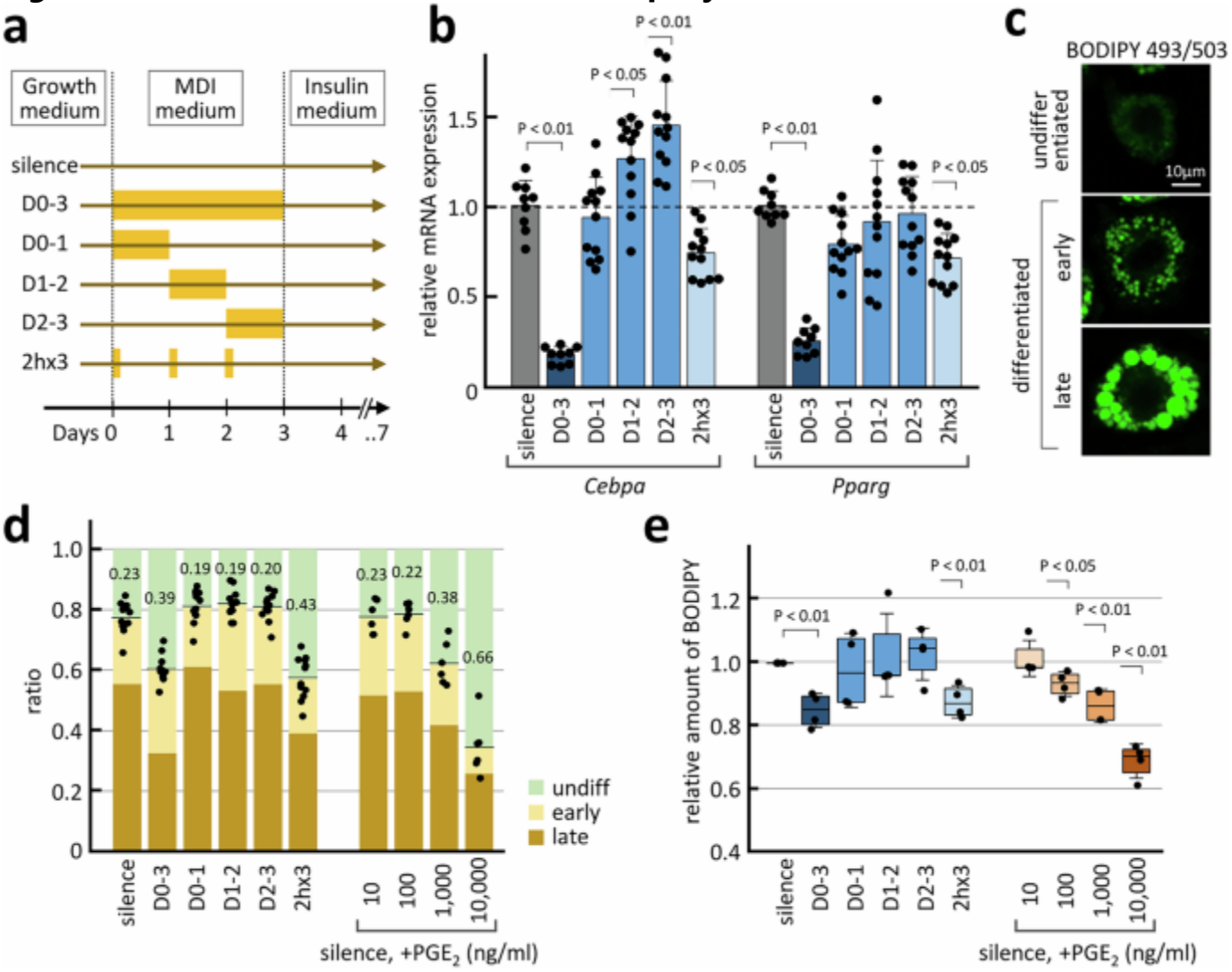
The cell-type specificity associated with the activation of this pathway by acoustic stimulation was examined using several cell lines, including epithelial, stromal, fibroblast, and neuroblast cells. The effect of acoustic stimulation on FAK Y397 phosphorylation, *Ptgs2* expression, and PGE_2 biogenesis was evaluated (Fig. 4b and Supplementary Fig. 8), revealing a markedly higher response in 3T3-L1 preadipocytes.

Suppression of adipocyte differentiation by acoustic stimulation

Adipocyte differentiation is affected by PGE_2 via EP4 receptor signalling[24,25]. *Ptgs2* expression is suppressed in developed white adipose tissues, which is directly related to reduced PGE_2 production and increased fat mass in the tissue[26]. Therefore, adipocyte differentiation is directly affected by PGE_2 production under the control of *Ptgs2*, suggesting the potential for regulating adipocyte activity through acoustic stimulation.

Adipocyte differentiation cultures using 3T3-L1 cells were subjected to acoustic stimulation. When the cell density reached ~70%, the medium was replaced with methylisobutylxanthine, dexamethasone, insulin (MDI)-containing differentiation induction medium and incubated for 3 days, followed by incubation in differentiation-enhancing medium containing insulin alone for four additional days; 440 Hz sine-wave sound was emitted at 100 Pa during the 3-day culture in MDI differentiation induction medium according to the following schedule: continuous emission during days (D) 0–3 (72 h), D0-1 (24 h), D1-2 (24 h), and D2-3 (24 h) or periodic emission for 2 h every day (2 h × 3; Fig. 5a). The effect of acoustic stimulation on adipocyte differentiation was evaluated by determining the expression levels of the marker genes, CCAAT/enhancer-binding protein α (*Cebpa*) and peroxisome proliferator-activated receptor γ (*Pparg*). Quantitative PCR analyses revealed considerable suppression of both genes on D3 in the D0–3 sample, exhibiting relative expression levels of 0.18 and 0.26 for *Cebpa* and *Pparg* (Fig. 5b). The 2 h × 3 sample exhibited approximately 30% suppression of both genes. The D0-1, D1-2, and D2-3 samples did not show statistically significant suppression of either gene, suggesting the need for persistent acoustic stimulation to achieve an efficient cell response.

Fig. 5: Effect of acoustic stimulation on adipocyte differentiation.



a Time course of the acoustic stimulation applied in this study. Stimulation periods are indicated in yellow. **b** Relative mRNA expression levels of adipocyte differentiation marker genes, *Cebpa* and *Pparg*, on differentiation day 3 of 3T3-L1 cells as revealed using quantitative PCR analyses. Bars represent +SD from 3 biological replicates of ≥3 independent experiments, and statistical significance compared with silence (grey) was evaluated using one-way ANOVA followed by Tukey's HSD test. **c** Lipid staining images of 3T3-L1 cells labelled with BODIPY 493/503. Images of undifferentiated, early differentiated, and late differentiated cells are shown. **d** Ratio of undifferentiated (green), early differentiated, and late differentiated (light and dark brown) 3T3-L1 cells on day 7. Acoustic stimulation conditions or PGE_2 concentrations supplemented in the MDI medium are indicated. Data

from three biological replicates of three (acoustic stimulation) and two (PGE_2 stimulation) independent experiments are presented. Dots represent each data point for the border of undifferentiated and differentiated cells. The ratio of undifferentiated cells is indicated. **e** The relative amount of lipid accumulation in day 7 cells was quantified by measuring the fluorescence intensity of BODIPY 493/503 extracted in 2-propanol after cell staining. Box indicates an average and 25–75 percentiles; bars represent ±SD from four independent experiments; statistical significance compared with the silent sample was evaluated using Welch's *t*-test.

The cells were completely differentiated under the above-mentioned culture conditions for 7 days, with or without acoustic stimulation. After D4, acoustic stimulation could not be applied owing to attenuated cell adhesion along with adipocyte differentiation, often resulting in the detachment of cells from the culture dish. Lipid accumulation was monitored by staining the cells with the nonpolar fluorescent dye, BODIPY 493/503, and classified into undifferentiated (no lipid droplet), early (~several micrometre lipid droplets), and late (many lipid droplets >10 μm in size) stages of adipocyte differentiation (Fig. 5c). When D0–3 acoustically stimulated cells were cultured until D7, the ratio of cells that remained undifferentiated increased significantly from 0.23 to 0.39 compared with that under the silent condition (Fig. 5d). Periodic 2 h × 3 stimulation also efficiently increased the ratio of the undifferentiated cell population to 0.43, whereas none of the one-day stimulations significantly altered the differentiation states. The effects of D0–3 and 2 h × 3 were comparable to those observed after the addition of 1000 ng/ml PGE_2 to the MDI medium. The amount of lipids accumulated in the cells was quantified by measuring the fluorescence intensity of the BODIPY 493/503 dye extracted with 2-propanol after staining. The relative amount of the signal revealed that D0–3 and 2 h × 3 acoustic stimulations suppressed lipid accumulation by 13−15% (Fig. 5e), equivalent to that observed after adding 1000 ng/ml PGE_2 and consistent with the microscopy results (Fig. 5d). The increase in the PGE_2 concentration due to acoustic stimulation remained at <100 ng/ml even after 3 days (Fig. 3g). Thus, the high efficiency of acoustic stimulation in

suppressing adipocyte differentiation is indicative of the involvement of other pathway(s) in acoustic signal transduction, which are yet to be identified.

Discussion

In this report, we revealed the properties, mechanisms of action, and effects of cell-level responses to the audible range of acoustic stimulation. All three sound factors (frequency, intensity, and waveform) affected gene response patterns, albeit in slightly different manners. Comparisons of 440 Hz and 14 kHz sound effects indicated that the early gene responses were similar, whereas frequency-specific responses were more prominent later (Fig. 1c–f). The effects on cell morphology within an hour were also similar among different frequencies (Fig. 3c), suggesting a cytoskeleton-linked shared sound response mechanism for the early-response and unknown mechanisms that trigger frequency-specific cell responses in longer timeframes. Early-response genes were more enriched in those involved in cell migration and adhesion (Fig. 1g), further supporting this idea. Evaluation of the gene responses at shorter time points revealed that 2 h was a reasonable timeframe to detect the expression of early-response genes, as two marker genes *Ptgs2* and *Ctgf* showed statistically significant responses in 1–2 h after the acoustic stimulation (Supplementary Fig. 9).

The generation of acoustic waves in water inevitably accompanies fluid movement. Although it is impossible to experimentally assess the sole effect of the compressional wave free of shear stress caused by the flow, comparison of the cell responses for 440 Hz and 14 kHz sound waves strongly suggests that many of the cellular responses observed in this study were induced by the compressional waves. When comparing acoustic waves with the same intensity, the amplitude of particle displacement of the sine wave is inversely proportional to the sound frequency. Thus, under the same 100 Pa output, a 440 Hz sound wave will have a 32-fold larger particle displacement amplitude than that of a 14 kHz sound wave and generate much larger shear stress for the cells. Therefore, cell responses caused by the shared stress are expected to be much higher at 440 Hz than those at 14 kHz. The correlation analyses of gene responses in response to 440 Hz and 14 kHz sound waves revealed dispersed distribution (Fig. 1f), with approximately half of genes (45.5%)

showing stronger response to 14 kHz stimulation than to 440 Hz stimulation (Supplementary Fig. 10a). Histogram showing the differences in the absolute response at 440 Hz from that at 14 kHz revealed normal distribution with the peak value of 0.06 (Supplementary Fig. 10b). Therefore both 440 Hz and 14 kHz stimulation induced similar levels of unique gene responses, implying that compressional wave is the major cause of these gene responses. This interpretation is also supported by an annotation analysis. Among 254 genes annotated as "response to fluid shear stress (GO:0034405)" in the gene ontology database[27], only 3 genes overlap with sound-sensitive genes identified in this study (Fig. 1d, e). This annotation category was not found in the top 40 annotation clusters enriched in the sound-sensitive genes, suggesting a minimal influence of the fluid shear force in our acoustic experimental condition. Notably, larger effects of the fluid movement may be included in the acoustic stimulation at lower frequencies in general. Further studies comparing different frequencies and output intensities will be useful to precisely estimate the effect of the fluid movements and elucidate the differences in results from those of compressional wave.

The effects of the different waveforms may be linked to different frequencies. Triangular and square waves contained more high-frequency overtone series than the pure sine wave (Supplementary Fig. 4); therefore, cell responses to triangular or square waves may include the effect of high-frequency waves. Comparison of the gene responses to 440 Hz and 14 kHz sound waves revealed higher correlation for square and triangular waves than sine wave, with the correlation coefficients of 0.76, 0.74, and 0.68 for square, triangular, and sine waves, respectively against 14 kHz, supporting this interpretation.

Considering the nature of acoustic waves and certain overlaps between sound-sensitive and mechanosensitive genes, the sound response mechanism is assumed to partially involve mechanotransduction. Two sound response marker genes identified in this study, *Ptgs2* and *Ctgf*, are mechanosensitive and are involved in responses to forces derived from cell-matrix interactions, such as stretch, compression, fluid shear stress, and matrix rigidity[28,29,30]. FAK is also involved in mechanosensing and regulates cell migration via Y397 phosphorylation, as observed in migrating fibroblasts[31]. In general FAK-dependent mechanical sensing is dependent on cell confluence, as FAK is

mainly involved in cell-matrix communication in a sparse condition, which is replaced to cell-cell communication at high confluence[32]. FAK-dependent gene responses such as *Ptgs2* and *Ctgf* under the condition of low as well as high confluence (Fig. 2f) imply a novel form of FAK-dependent signal transduction triggered by acoustic stimulation. Taken together with the gene and cell morphological responses (Figs.1 and 3), the effect of acoustic stimulation may be similar to that of a stiff matrix. Our observation that acoustics negatively impact adipocyte differentiation (Fig. 5) supports this idea, as a stiff matrix also suppresses adipocyte differentiation[33].

Low-intensity pulsed ultrasound (LIPUS) at several MHz frequencies also induces *Ptgs2* and *Ctgf* expression in bone cells, such as osteoblasts and chondrocytes[34,35]. Several studies have reported the effects of LIPUS in suppressing adipocyte differentiation. In response to LIPUS transmitted at different MHz frequencies, three cellular pathways are reportedly activated: ERK signalling through Rho-associated kinase or insulin receptor signalling[36,37], YAP nuclear translocation[37], and histone deacetylase 1[38], all resulting in the suppression of adipocyte differentiation. The focal adhesion-mediated pathway revealed in this study is different from the pathway activated in response to LIPUS, which is expected, considering an approximately 10^4-fold difference in the frequency between LIPUS and audible sound sources used in this study. Several genes showed unique and characteristic responses to different sound stimulations (Fig. 1, Supplementary Fig. 3), suggesting a unique feature of acoustic stimulation that differs from other mechanical stimuli. Considering the infinite sound pattern with both temporal and compositional variations, acoustic stimulation may induce diverse cellular responses and, therefore, is an intriguing tool for cell manipulation such as living tissue engineering, regenerative medication, artificial tissue culture and related biotechnology industry.

Differences in sensitivity to acoustic stimulation in different cell types likely reflect structural and functional heterogeneity of the focal adhesion. The size, number, and molecular components of the focal adhesions vary significantly and are closely related to the cell motility and adhesion properties[39]. Adhesive stromal and its derivative cells, including fibroblasts, myoblasts, osteoblasts, and adipocytes, were highly sensitive to acoustic stimulation (Fig. 4b), possibly

due to their highly adhesive and motile nature that is essential to develop active focal adhesions. In contrast, epithelial and neuroblastoma cells, which are less mobile or less adhesive, were relatively insensitive. Although this focal adhesion-dependent pathway preferentially acts in stromal cell lines, other sound perception pathways may be active in other cell types. Further studies comparing the global gene expression patterns of different cell lines in response to different sound patterns unveil mechanisms underlying cell responses to sound.

Sound exists universally in the material world; thus, life forms are exposed to this physical energy from their inception. It is, therefore, not surprising that living organisms develop systems to utilise sound as an environmental stimulus and optimise activities at the cellular level. Our findings reveal the nature of cells that sense acoustic information to orchestrate inner activities and mark the beginning of research focusing on the fundamental relationship between life and sound.

Methods

Direct sound emission system

The detailed setup is shown in Supplementary Fig. 2. In short, a vibrational transducer (Mini-shaker Type 4810, Brüel & Kjær, Nærum, Denmark) attached to a laboratory scissor jack was inversely fixed to a small metal shelf. A diaphragm custom-made with PEEK (Nippon Chemical Screw, Tokyo, Japan) was selected by comparing the properties of a plate made of several different materials. The sound signal was output using a conventional MP3 player, adjusted by an amplifier (AP15d, Fostex, Tokyo, Japan), and input into the transducer. The position of the head of the diaphragm was adjusted for attachment to the culture medium to generate the acoustic waves directly in the medium. This system was primarily used in this study.

Indirect sound emission system

A full-range active loudspeaker (6301NB, Fostex, Tokyo, Japan) was set under a small metal shelf. The sound signal was output using a conventional MP3 player, adjusted by an amplifier (AP15d, Fostex, Tokyo, Japan), and input into the loudspeaker.

Sound sources

Single-frequency and noise sound signals were generated using the Tone Generator software (NCH Software, Canberra, Australia), with a sampling rate of 44,100 Hz. A total length of 60 s was repeatedly emitted. All sound data used in this study are available in Supplementary Audio 1–5.

Sound intensity measurement in water

Sound was acquired in water using a hydrophone (AQH-100, AquaSound, Kobe, Japan) and processed using an Aquafeeler monitoring system (AquaSound, Kobe, Japan) and a digital converter (SE-U33GX, Onkyo, Osaka, Japan). The signal was recorded and analysed using the SP4Win custom software (NTT Advanced Technology Corporation, Tokyo, Japan) to obtain the root mean square (RMS) value. Considering the sensitivity of the hydrophone to be -207.3 dB re. 1 V/μPa, it detected 15,311 Pa/V. The output with 1 V of a 1 kHz sine-wave standard signal from the Aquafeeler was used for calibration, according to which 1 V = 19929.2 RMS. The sound pressure obtained was 0.768 Pa/RMS using this system. The pressure level obtained under the silent condition was subtracted as the background noise.

Cell culture, drugs, PGE_2 quantification, and western blotting

C2C12 (RCB0987), NIH3T3 (RCB2767), MC3T3-E1 (RCB1126), NRG (RCB1921), ST2 (RCB0224), and NB2a (RCB2639) were obtained from Riken Bioresource Research Center (Ibaraki, Japan), and 3T3-L1 (JCRB9014) was obtained from Japanese Collection of Research Bioresources (Osaka, Japan). The cells were cultured in Dulbecco's modified Eagle's medium (DMEM; D6046 and D6429, Sigma-Aldrich, St. Louis, MO, USA) supplemented with 10% foetal bovine serum (BCBZ5443, Sigma-Aldrich, St. Louis, MO, USA), penicillin-streptomycin (26253-84, Nacalai Tesque, Kyoto, Japan), and amphotericin B (SV30078.01, Cytiva HyClone, MA, USA) in a water-jacketed incubator supplied with 5% CO_2. The cells were carefully maintained at a maximum of 60% confluence to avoid the effect of contact inhibition and spontaneous differentiation. Thereafter, 2 μM Y15 (S5321, Selleck, Houston, TX, USA), 2 or 10 μM L161.982 (SML0690, Sigma-Aldrich, St. Louis, MO, USA), and 10−10,000 ng/ml PGE_2 (29334-21, Nacalai Tesque, Kyoto, Japan) were added when required. The amount of PGE_2 in the culture medium was quantified using a PGE_2 CLIA kit (ADI-910-001,

Enzo Life Sciences, Farmingdale, NY, USA) according to the manufacturer's instructions. Western blotting was performed using anti-phospho Y397 FAK (ab81298, Abcam, Cambridge, UK), anti-FAK (13009, Cell Signaling Technology, Danvers, MA, USA), and anti-β-actin (A5441, Sigma-Aldrich, St. Louis, MO, USA) antibodies. Horseradish peroxidase-conjugated anti-rabbit IgG (A27036, Invitrogen/Thermo Fisher Scientific, Waltham, MA, USA) and anti-mouse IgG (Cytiva, MA, USA) were used as secondary antibodies and detected using the Chemi-Lumi One L reagent (07880, Nacalai Tesque, Kyoto, Japan) and LAS-3000 mini imaging system (FujiFilm, Tokyo, Japan).

RNA-sequencing analysis

C2C12 cells in a 30 mm dish that were ~40% confluent were treated with a 440 Hz sine-wave sound, 14 kHz sine-wave sound, and white noise at 100 Pa. After continuous sound emission for 2 and 24 h, total RNA was extracted using an RNeasy kit (74104, Qiagen, Hilden, Germany). The RNA library was prepared using the NEB Next Ultra II Directional RNA library prep kit for Illumina (E7760, New England BioLabs, Ipswich, MA, USA). RNA-sequencing was performed using NextSeq500 (Illumina, San Diego, CA, USA), with a single-end read and high output for 75 cycles. Trimming of noise signals (poly G), low-quality reads (~30 bases), and an additional base at the 76th position was performed using Cutadapt[40] and Trimmomatic[41]. Mapping and identification of differentially expressed genes were performed using the CLC Genomics Workbench 21 software (Qiagen, Hilden, Germany). In short, reads were mapped on the mouse genome sequence (GRCm38.91) and normalised by the trimmed mean of M values method. Samples from three independent experiments were analysed. Genes with >1.2 fold change (maximum false discovery rate [FDR]-$P < 0.05$) in 2 h sound-stimulated samples were selected as early sound response genes, and those with >1.5 fold changes (FDR-$P < 0.05$) after 24 h were selected as late sound response genes. Annotation analysis was performed using the Metascape gene annotation tool[13] with the list of sound response genes.

Reverse transcription-coupled quantitative PCR (RT-qPCR) analysis

Total RNA was extracted using the RNeasy kit (74104, Qiagen, Hilden, Germany) and used as a template for RT-qPCR using a One Step SYBR

PrimeScript Plus RT-PCR kit (RR096B, Takara Bio, Shiga, Japan) and an RT-qPCR system (LightCycler 480 and LightCycler 96, Roche, Basel, Switzerland). The primer sequences used to detect mouse mRNAs are listed in Table 1. Melting curve analysis was performed to assess the quality of the amplicons, and only single-peak runs were selected. The amounts of loaded templates under each condition were calibrated using the *Actb* mRNA level, and values relative to the mRNA levels from the silent condition were obtained.

Table 1 Sequences for primers used in qPCR analysis

Microscopic observation and processing

The direct sound emission system was mounted on the stage of a confocal laser-scanning microscope (FV-1200, Olympus, Tokyo, Japan) equipped with a heating stage. The diaphragm was inserted into the heating chamber through a hole in the lid and covered with aluminium foil to stabilise the temperature (Supplementary Fig. 7). To cancel the effect of sound vibrations disturbing the image acquisition, three line scans and four z-stack projections were averaged. Images were acquired every minute for 1 h. To detect the cell edge, the images were binarised and traced. To obtain the expanded and retracted areas, each consecutive image was subtracted and presented as green and red, respectively. The ImageJ software[42] was used to adjust, binarise, subtract, and quantify the signals.

Adipocyte differentiation and evaluation

3T3-L1 cells were cultured to ~70% confluence and incubated with MDI differentiation induction medium containing 0.5 mM methylisobutylxanthine (ab120840, Abcam, Cambridge, UK), 1 µM dexamethasone (ab120743, Abcam, Cambridge, UK), and 10 µg/ml insulin (ab123768, Abcam, Cambridge, UK) for 3 days. The medium was then replaced with a differentiation-enhancing medium containing 10 µg/ml insulin alone for four additional days. For lipid staining, the cells were incubated with 0.5 mM BODIPY 493/503 (D3922, Invitrogen/Thermo Fisher Scientific, Waltham, MA, USA) in serum-free DMEM for 5 min, washed twice with phosphate-buffered saline, and observed under a confocal laser-scanning microscope (FV-1200, Olympus, Tokyo, Japan). The

BODIPY-stained cells were incubated with 100% 2-propanol for 5 min to extract the dye, and the fluorescence intensity was measured using a plate reader (TriStar 3, Berthold, Baden-Württemberg, Germany).

Simulation analysis of acoustic transmission in an elastic object via physical contact

An elastic object of 0.001 m^3 volume with a 1×10^5 N/m^2 shear elastic constant—stiffness typical for soft biological tissues used in simulation analyses[43]—was subjected to physical contact with an impact ball (YI-01, Rion, Tokyo, Japan) that provides maximum impact force corresponding to that of trotting male humans[44]. The analysis was performed based on the vibroacoustic finite-difference time-domain method[45].

Simulation analysis of acoustic propagation using an indirect sound emission system

The sound source and detection points were set at an acoustic field of 252,000 mm^3. The detection point was located at the centre of the water, and the sound source was located 50 mm from the detection point. The culture dish was made of acrylic plastic, and the Young's modulus, Poisson's ratio, and density were set to 3.2 GPa, 0.35, and 1190 kg/m^3, respectively. The analysis was performed based on the finite element method using commercially available software (COMSOL Multiphysics 6.1, Comsol, Burlington, MA, USA).

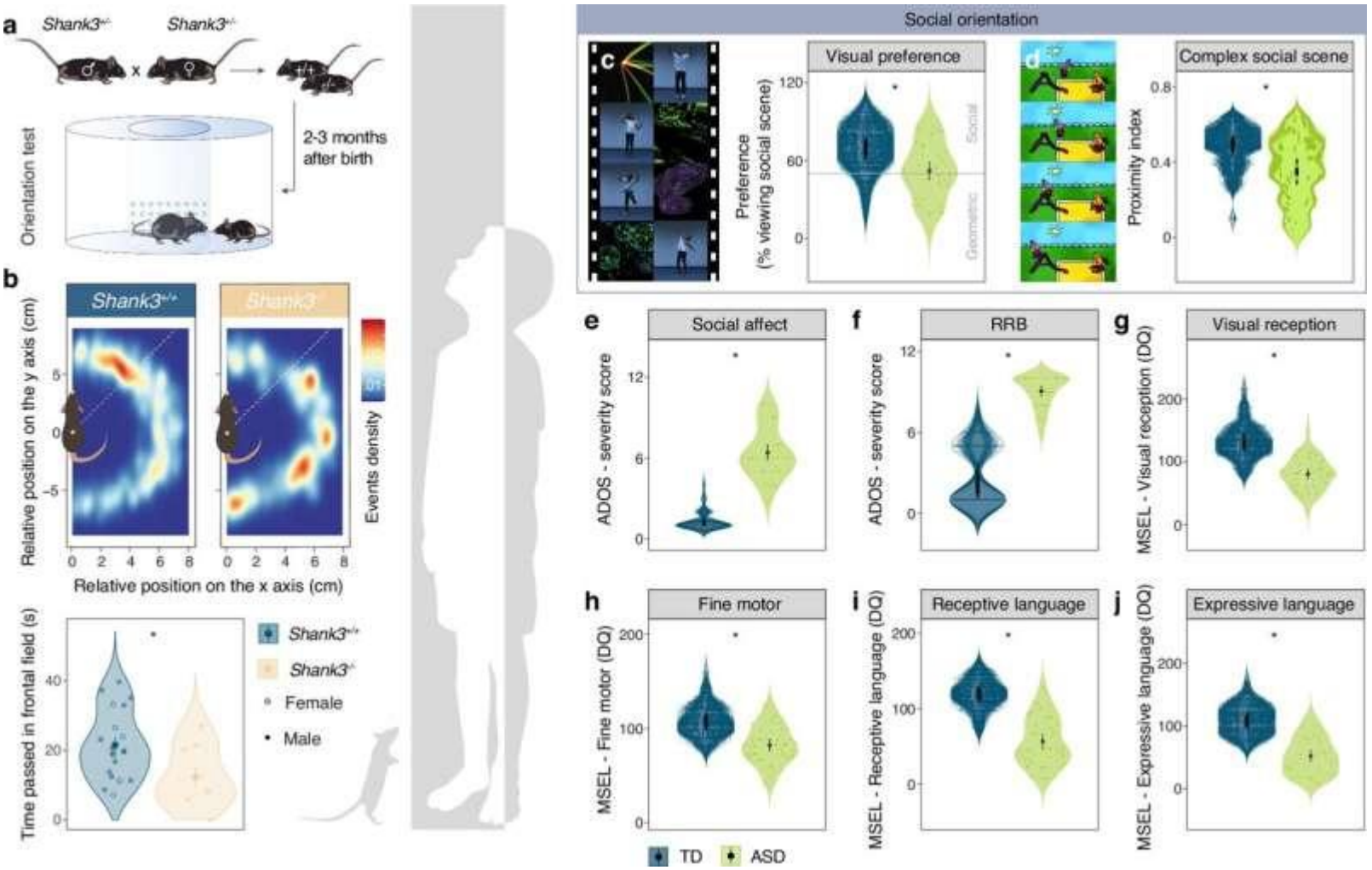
Statistics and reproducibility

The normality of the data distribution was evaluated using the Shapiro–Wilk test. One-way ANOVA followed by Tukey's honestly significant difference (HSD) test was applied for normally distributed samples, and non-parametric Welch's *t*-test was applied for non-normally distributed samples to evaluate statistical significance. Sample sizes and number of replicates were described in each figure legend.

APRIL 14, 2025

Autism: The neural origin of the social bond

by University of Geneva



Shank3 KO mice and autistic children show deficits in social orientation. Credit: *Molecular Psychiatry* (2025). DOI: 10.1038/s41380-025-02962-w

From birth, human survival depends on the ability to engage with others. This ability, which is essential for development, seems to be impaired very early on in children with autism spectrum disorders (ASD), who show limited interest in social stimuli from their first year of life.

To understand the neurobiological basis of this phenomenon, scientists at the University of Geneva (UNIGE) combined data from clinical and animal research. They identified a defect

in a communication pathway between two brain structures that prevents rapid redirection of attention, a key mechanism for decoding social interactions.

These results, published in the journal *Molecular Psychiatry*, pave the way for better prediction of development and more targeted interventions.

It is currently estimated that 1 child in 36 develops an autistic disorder, of whom one-third are at risk of cognitive impairment. "In the children who show a delay, the cognitive difficulties are the consequence of a lack of understanding of social interactions," explains Camilla Bellone, Associate Professor in the Department of Basic Neurosciences at the UNIGE Faculty of Medicine, and co-last author of the study.

"We learn through interaction with others. As young children with ASD are less oriented towards social cues very early on, they are less likely to develop the tools that enable them to navigate the social world and learn." While the consequences of this lack of social interest on development are well known, the neurobiological causes are much less so.

Studying brain networks with mouse models

At the UNIGE Faculty of Medicine, the Synapsy Center for Research in Neuroscience for Mental Health brings together neuroscientists and psychiatrists in a joint network. This sharing of expertise has led to a major discovery for understanding the very essence of social interaction: The ability to maintain a social interaction depends on the speed with which attention can be shifted from one stimulus to another.

"In mice lacking the Shank3 gene—the most common single-gene-cause of ASD found in humans—we observe orientation deficit towards other mice, which reflects the alterations in social interactions already described in children with ASD. These mice therefore represent a good model for the study of ASD," explains Marie Schaer, Associate Professor in the Department of Psychiatry at the UNIGE Faculty of Medicine and co-last author of the study.

Impaired neuronal synchronization

In previous research, Bellone's team identified a neuronal communication pathway whose role is to send information between the superior colliculus, a brain structure linked to orientation, and particularly to social orientation, and the ventral tegmental area, linked to the reward system.

"This time, we were able to show in our mouse model of ASD that a lack of neural synchronization in the superior colliculus altered the exchange of communication between the two cerebral areas, resulting in defects in the orientation and social behavior of individuals."

These experiments were carried out in vivo using miniaturized microscopes that enable the monitoring of neural activity in moving animals. They were conducted by Alessandro Contestabile, co-first author of the study and a post-doctoral researcher in Bellone's laboratory.

A specific protocol for ASD children

To confirm this hypothesis in humans, Nada Kojovic, a researcher in Schaer's team and co-first author of the study, developed an original protocol for obtaining brain MRIs without sedation in children aged 2 to 5 years.

"It is obviously impossible to ask such young children to remain motionless in the MRI scanner for the 30 minutes needed to obtain the images," she explains. "We therefore developed a habituation protocol, fitted out the MRI room and worked closely with the families to provide optimum conditions for the child to fall asleep, which worked very well for over 90% of the children for whom we obtained very good quality MRI images."

The two teams observed that the circuit changes identified in mice were identical in the children. Furthermore, the level of connectivity in this circuit makes it possible to predict their cognitive development in the following year. While it is not yet possible to intervene directly in this brain network, this discovery provides a guide to behavioral interventions, in particular, to reinforce children's ability to redirect their attention from one thing to another rapidly from an early age.

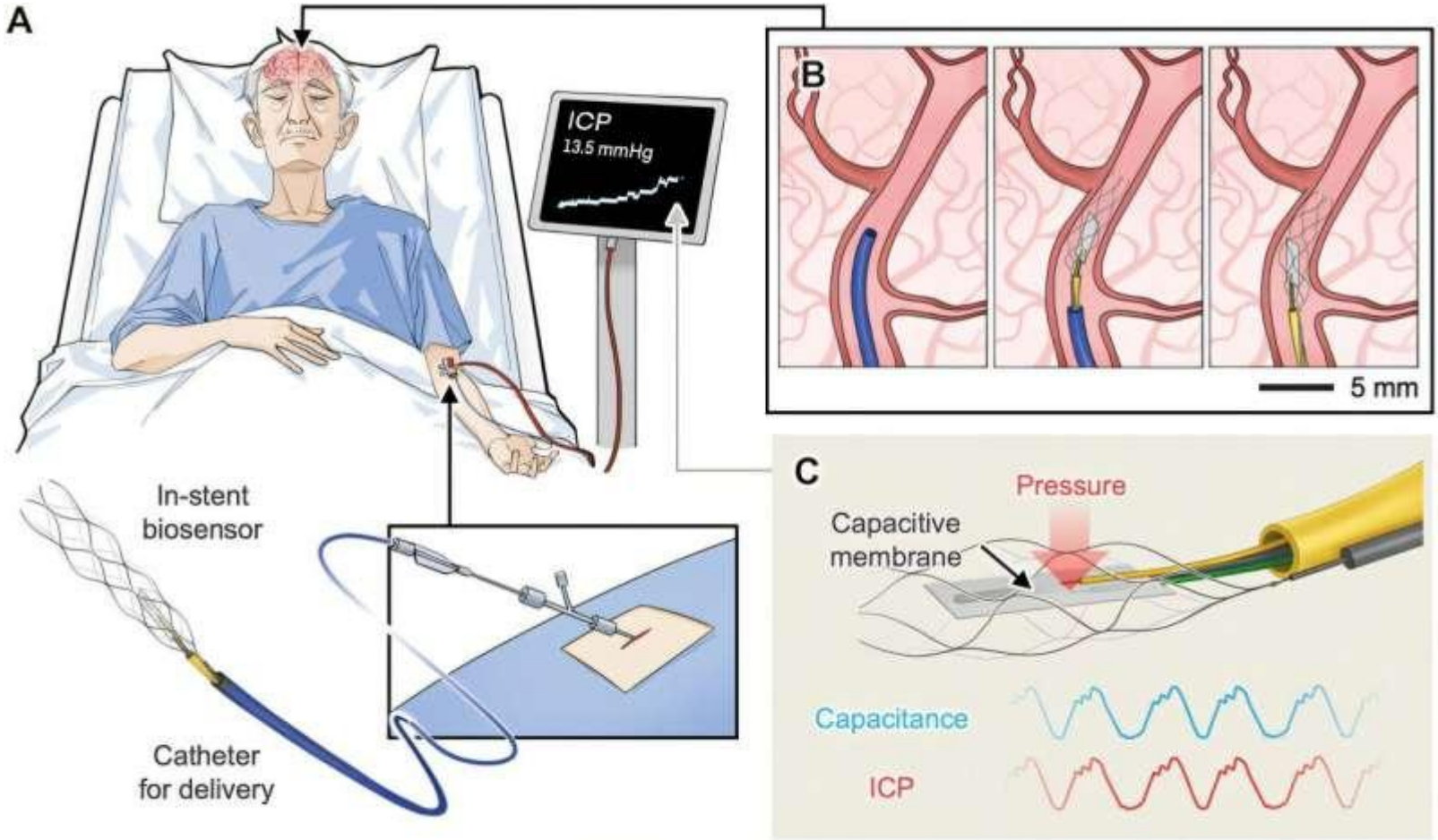
An intensive treatment method developed in the United States and used in Geneva which requires 20 hours a week for two years, has already proved its worth. With early intervention, the children gain an average of 20 IQ points, and 75% of them can go on to attend ordinary school.

More information: Alessandro Contestabile et al, Translational research approach to social orienting deficits in autism: the role of superior colliculus-ventral tegmental pathway, *Molecular Psychiatry* (2025). DOI: 10.1038/s41380-025-02962-w
Journal information: Molecular Psychiatry
Provided by University of Geneva

APRIL 14, 2025

Ultra-thin, flexible silicone nanosensor could have huge impact on brain injury treatment

by Tess Malone, Georgia Institute of Technology



Overview of a non-surgical membrane bioelectronic system for continuous ICP monitoring. Credit: *Advanced Healthcare Materials* (2025). DOI: 10.1002/adhm.202404680

A car accident, football game, or even a bad fall can lead to a serious or fatal head injury. Annually, traumatic brain injuries (TBI) cause half a million permanent disabilities and 50,000 deaths. Monitoring pressure inside the skull is key to treating TBI and preventing long-lasting complications.

Most of these monitoring devices are large and invasive, requiring surgical emplacement. But Georgia Tech researchers have recently created a sensor smaller than a dime. The miniature size offers huge benefits.

"Surgery means extensive recovery time and can significantly impact patient health. Our system doesn't require surgery because we use a conventional stent, the catheter, as a delivery vehicle," said W. Hong Yeo, the Harris Saunders Jr. Endowed Professor and an associate professor in the George W. Woodruff School of Mechanical Engineering.

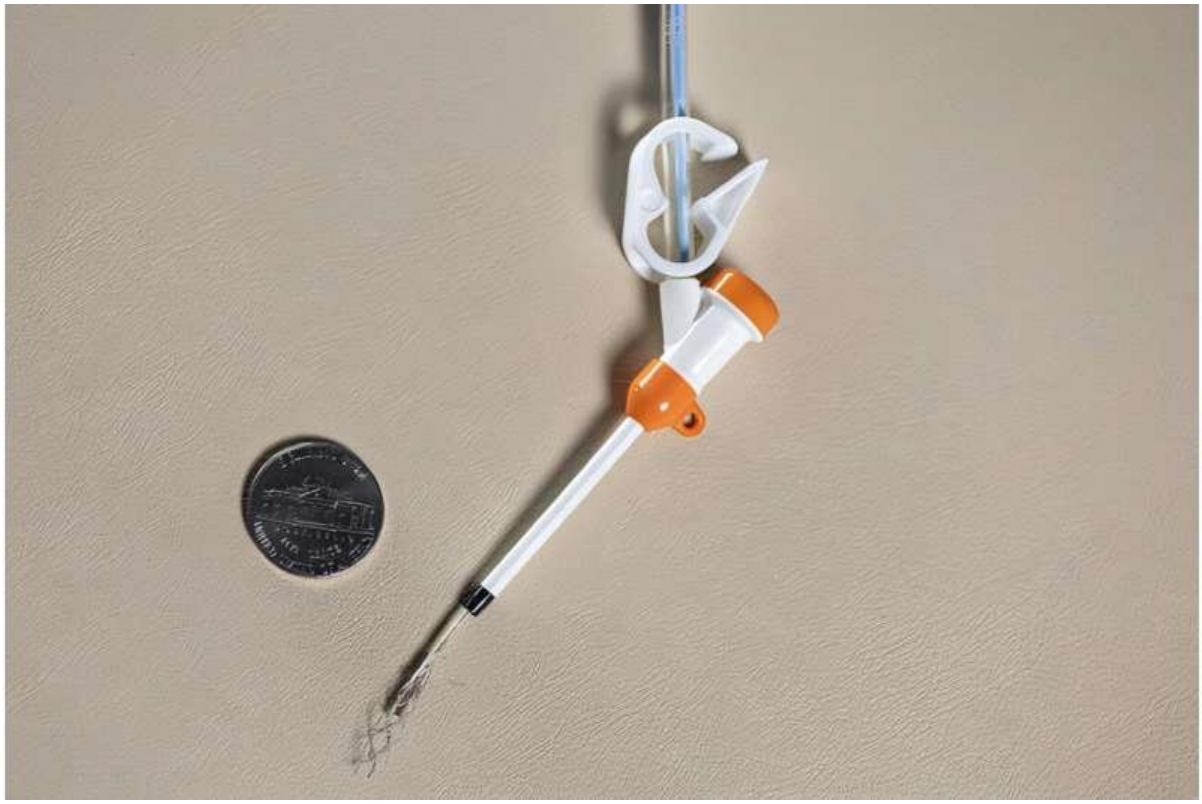
Made from ultra-thin, flexible silicone, these nanosensors can be embedded in almost anything, from pacifiers to catheters. But size was just one element the researchers needed to consider when developing this device; accuracy was just as important.

"The key challenge was to make tiny sensors but at the same time maintain the sensitivity and functionality at a high level," said Yeo, who also directs the Wearable Intelligent Systems and Healthcare Center (WISH Center) at the Institute for Matter and Systems.

Once the researchers' catheter is in the patient's skull, the sensor has the potential to continuously gather data at an especially sensitive rate compared to traditional devices. With this sensor, even the smallest pressure changes could register and alert clinicians that further treatment is needed.

Yeo and his collaborators published this research in *Advanced Healthcare Materials* in February, when it was selected for the inside front cover.

The inspiration for the catheter came from co-author Deok Hee Lee, a South Korean physician Yeo met at a conference where Yeo presented on these smaller sensors. The two have collaborated to bring nanotechnology to some of the most common medical problems Lee treats, such as monitoring intracranial pressure after TBIs, high blood pressure, and other ailments. Three years later, they developed this sensor.



The sensor is smaller than a dime. Credit: Christopher McKenney/Georgia Institute of Technology

Yeo thinks this is just the start of what they can track.

"We believe that this first development will bring new opportunities to measure signals with minimal complications caused by conventional surgery," he said.

While the researchers can't prevent TBIs, this device could help improve patient outcomes—and a less invasive procedure could lead to a more expansive future.

More information: Jimin Lee et al, Non-Surgical, In-Stent Membrane Bioelectronics for Long-Term Intracranial Pressure Monitoring, *Advanced Healthcare Materials* (2025). DOI: 10.1002/adhm.202404680

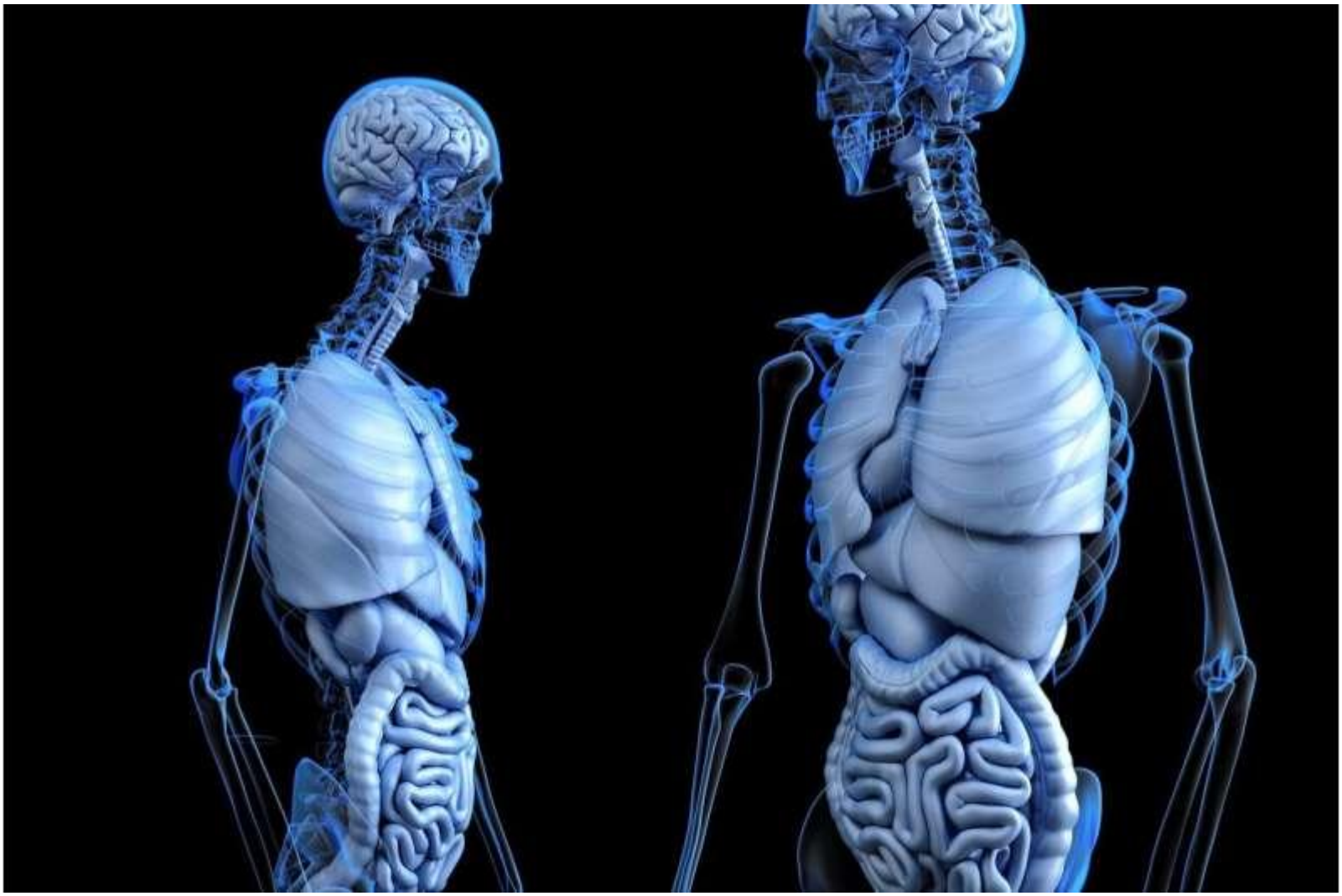
Journal information: Advanced Healthcare Materials

Provided by Georgia Institute of Technology

APRIL 14, 2025

Gut-brain link may affect behavior in children with autism

by University of Southern California



Credit: Pixabay/CC0 Public Domain

A new USC study suggests that gut imbalances in children with autism may create an imbalance of metabolites in the digestive system—ultimately disrupting neurotransmitter production and influencing behavioral symptoms.

The research, published in *Nature Communications*, adds to a growing body of science implicating the "gut-brain" axis in autism. The discovery raises the possibility of new treatment avenues. It's an example of how research at USC, and other universities, drives innovation and leads to discoveries that improve lives.

"We demonstrated that gut metabolites impact the brain, and the brain, in turn, affects behavior. Essentially, the brain acts as the intermediary between gut health and autism-related behaviors," said first author Lisa Aziz-Zadeh, a professor at the Brain and Creativity Institute at the USC Dornsife College of Letters, Arts and Sciences.

"Previous studies highlighted differences in gut microbiomes and brain structures in autism, but our research connects the dots."

The gut-brain connection is not as far-fetched as it might seem. From an evolutionary perspective, the gut was likely the first "brain," explained Aziz-Zadeh, who is also a professor at USC Dornsife's Department of Psychology and the USC Mrs. T.H. Chan Division of Occupational Science and Occupational Therapy.

In fact, most of the neurons from the gut send signals to the brain; there are actually more neurons in the gut than in the spinal cord. About 90% of the neural signals between the gut and brain travel from the gut to the brain, while only 10% go in the opposite direction.

This constant communication explains why we talk about "gut instinct" or "feeling it in your gut." Many emotions are processed through gut-related mechanisms, a concept known as interoception—the perception of internal bodily sensations.

For the study, researchers collected behavioral data, brain imaging data and stool samples from 43 children with autism and 41 neurotypical children aged 8-17. From the stool samples, they analyzed metabolites produced by gut bacteria that break down food in the digestive system.

The researchers then correlated these metabolites with brain differences observed in children with autism and their behavioral characteristics. They homed in on the "tryptophan pathway" by which tryptophan, an amino acid found in many foods, is broken down into several metabolites, including serotonin.

Serotonin is crucial for emotional processing, social interaction, learning and other brain functions. Since much of the body's serotonin originates in the gut microbiome, changes in gut health can influence serotonin production.

"We know that children with autism have brain differences—certain parts of their brain are either less active or more active compared to typically developing children," Aziz-Zadeh said.

"We also know they often experience gastrointestinal issues, such as constipation, stomach pain and other digestive problems. Additionally, autism is associated with various symptoms, including repetitive behaviors and social difficulties."

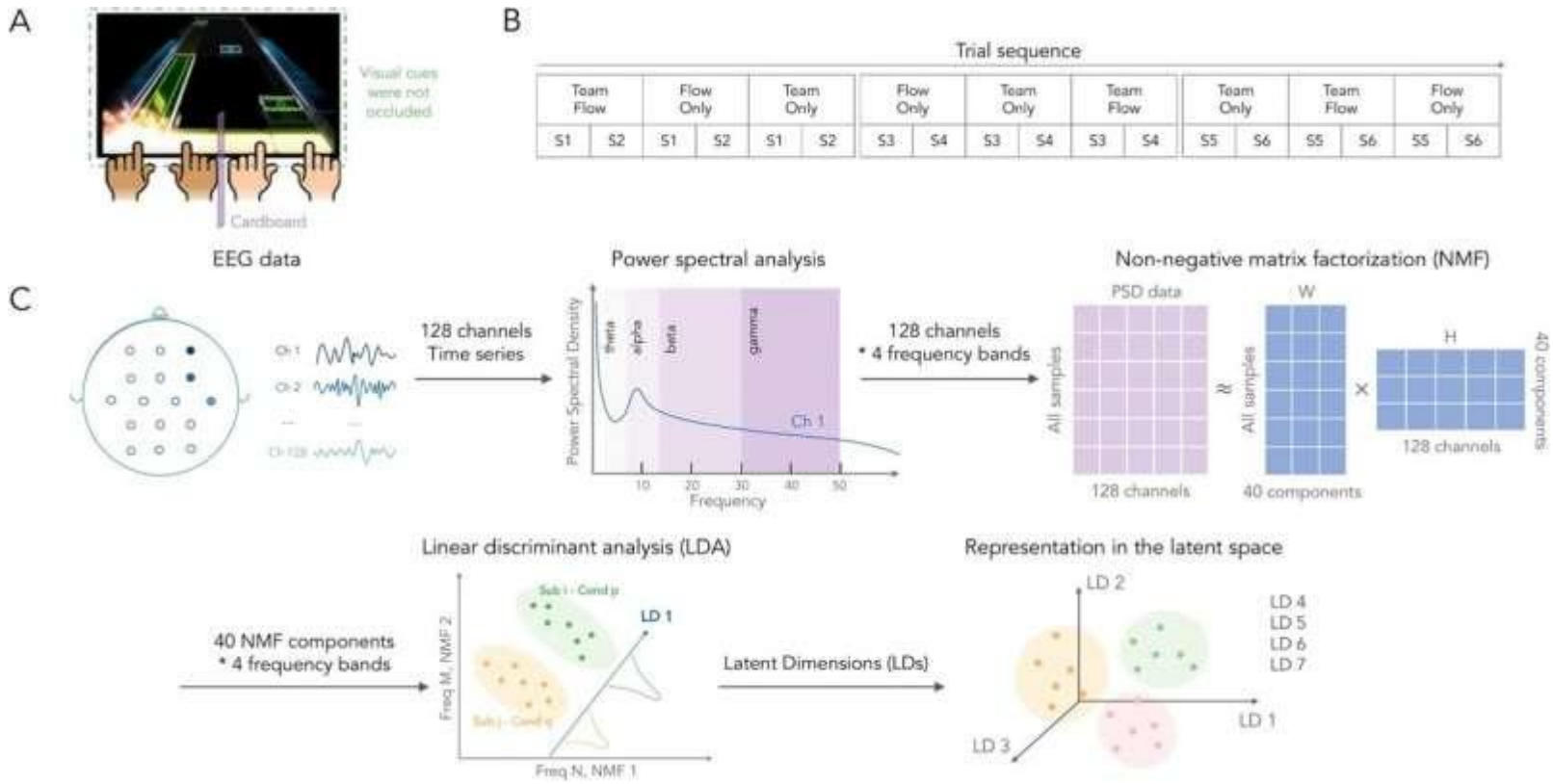
Sofronia Ringold, a doctoral student at the Brain and Creativity Institute who worked on the study, said she was excited by the possibility of interventions that might target the gut and influence neural activity and behavior "while also hopefully alleviating some of the symptoms that are the most uncomfortable for them."

More information: Lisa Aziz-Zadeh et al, Relationships between brain activity, tryptophan-related gut metabolites, and autism symptomatology, *Nature Communications* (2025). DOI: 10.1038/s41467-025-58459-1
Journal information: Nature Communications
Provided by University of Southern California

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

Brain's visual system adapts to ignore frequent distractions, study finds

by Susann Sika, Leipzig University

A subject wearing an EEG cap that allows simultaneous voltage measurements at 64 locations on the scalp. Credit: Peter Valckx, Vrije Universiteit Amsterdam

The human brain can learn through experience to filter out disturbing and distracting stimuli—such as a glaring roadside billboard or a flashing banner on the internet. Scientists at Leipzig University and Vrije Universiteit Amsterdam have used electroencephalography (EEG) to show that early visual processing in humans changes with repeated exposure.

Distractions are often easier to ignore after we have encountered them multiple times. This learned suppression is an important component of the human visual system, which is otherwise strongly influenced by voluntary attention control.

In a series of EEG experiments involving 24 female and male participants, the researchers investigated how learning influences attention to prominent distracting stimuli when these distractions frequently occur in specific locations.

The research is published in *The Journal of Neuroscience*.

"We found consistent evidence that learning alters the early responses of the visual system to these stimuli," says Dr. Norman Forschack from the Wilhelm Wundt Institute of Psychology at Leipzig University, one of the study's authors.

In the experiments, participants were asked to locate a specific target object—for example, a green circle among green diamonds. As part of the task, a distracting stimulus—such as a red diamond—was frequently placed in the same position.

Analysis of brain activity revealed that, over time, the brain began to suppress that position within the very first moments of visual processing. Participants also performed significantly better in locating the target object when the distracting stimulus appeared in the learned position, compared to when it appeared elsewhere.

"These findings show that our brain doesn't just react automatically to striking stimuli, but can also learn through experience to filter out distractions efficiently," explains Forschack. "Interestingly, we also observed reduced visual processing for target stimuli when they appeared in the position where the distractor had been frequently shown," he adds.

It remains unclear how this habitual attenuation of visual processing works in everyday life—for example, for commuters who repeatedly travel the same routes. According to the researchers, consistent design of roads and traffic environments could be beneficial for road safety.

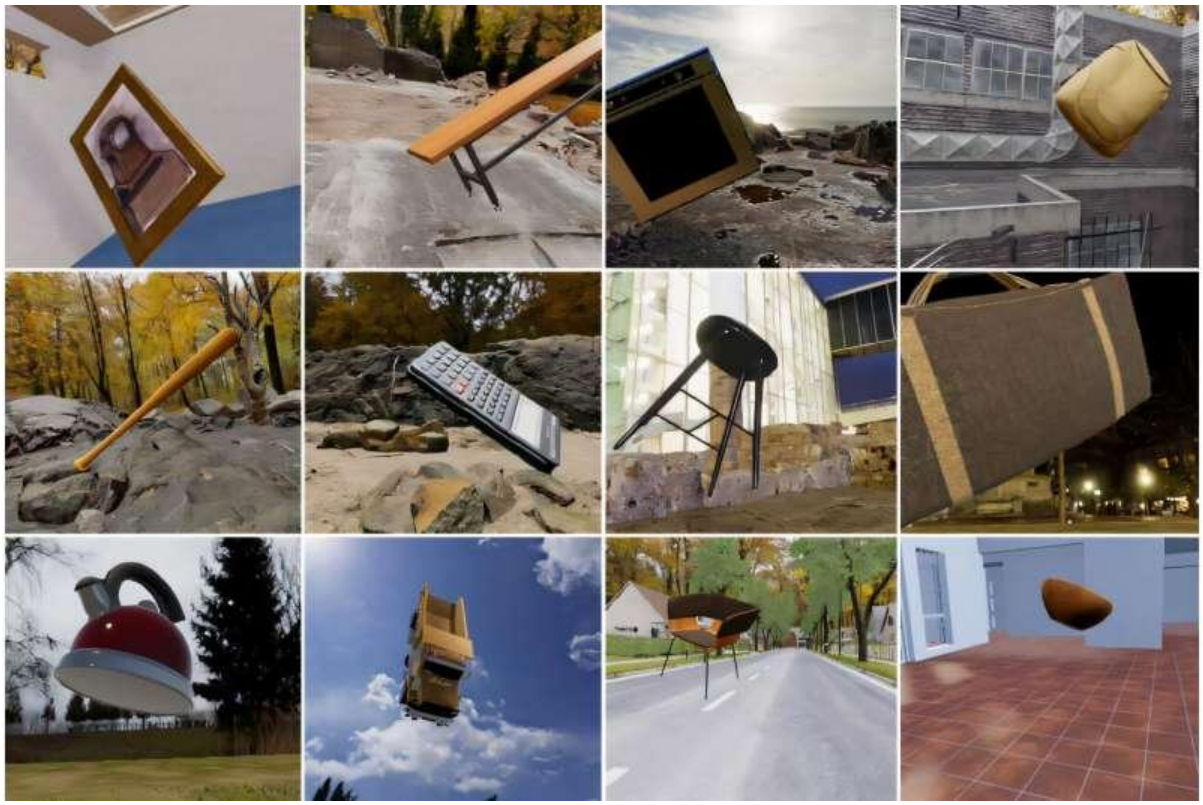
Dock Duncan of Vrije Universiteit Amsterdam, the study's lead author, concludes, "It is clear that people automatically recognize familiar user interfaces or textbook chapter layouts and find these useful, and that this effect is already reflected in basic visual processing."

More information: Dock H. Duncan et al, Learning modulates early encephalographic responses to distracting stimuli: a combined SSVEP and ERP study, *The Journal of Neuroscience* (2025). DOI: 10.1523/JNEUROSCI.1973-24.2025
Journal information: Journal of Neuroscience
Provided by Leipzig University

APRIL 15, 2025

A visual pathway in the brain may do more than recognize objects

by Anne Trafton, Massachusetts Institute of Technology



The models were trained on a dataset of synthetic images like the ones pictured, with objects such as tea kettles or calculators superimposed on different backgrounds. Researchers trained the model to identify one or more spatial features of an object, including rotation, location, and distance. Credit: Massachusetts Institute of Technology

When visual information enters the brain, it travels through two pathways that process different aspects of the input. For decades, scientists have hypothesized that one of these pathways, the ventral visual stream, is responsible for recognizing objects, and that it might have been optimized by evolution to do just that.

Consistent with this, in the past decade, MIT scientists have found that when computational models of the anatomy of the ventral stream are optimized to solve the task of object recognition, they are remarkably good predictors of the neural activities in the ventral stream.

However, in a new study, MIT researchers have shown that when they train these types of models on spatial tasks instead, the resulting models are also quite good predictors of the ventral stream's neural activities. This suggests that the ventral stream may not be exclusively optimized for object recognition.

"This leaves wide open the question about what the ventral stream is being optimized for. I think the dominant perspective a lot of people in our field believe is that the ventral stream is optimized for object recognition, but this study provides a new perspective that the ventral stream could be optimized for spatial tasks as well," says MIT graduate student Yudi Xie.

Xie is the lead author of the study, which will be presented at the International Conference on Learning Representations. The findings are published on the *arXiv* preprint server.

Beyond object recognition

When we look at an object, our visual system can not only identify the object, but also determine other features such as its location, its distance from us, and its orientation in space.

Since the early 1980s, neuroscientists have hypothesized that the primate visual system is divided into two pathways: the ventral stream, which performs object-recognition tasks, and the dorsal stream, which processes features related to spatial location.

Over the past decade, researchers have worked to model the ventral stream using a type of deep-learning model known as a convolutional neural network (CNN). Researchers can train these models to perform object-recognition tasks by feeding them datasets containing thousands of images along with category labels describing the images.

The state-of-the-art versions of these CNNs have high success rates at categorizing images. Additionally, researchers have found that the internal activations of the models are very similar to the activities of neurons that process visual information in the ventral stream.

Furthermore, the more similar these models are to the ventral stream, the better they perform at object-recognition tasks. This has led many researchers to hypothesize that the dominant function of the ventral stream is recognizing objects.

However, experimental studies, especially a study from the DiCarlo lab in 2016, have found that the ventral stream appears to encode spatial features as well. These features include the object's size, its orientation (how much it is rotated), and its location within the field of view. Based on these studies, the MIT team aimed to investigate whether the ventral stream might serve additional functions beyond object recognition.

"Our central question in this project was, is it possible that we can think about the ventral stream as being optimized for doing these spatial tasks instead of just categorization tasks?" Xie says.

To test this hypothesis, the researchers set out to train a CNN to identify one or more spatial features of an object, including rotation, location, and distance. To train the models, they created a new dataset of synthetic images. These images show objects such as tea kettles or calculators superimposed on different backgrounds, in locations and orientations that are labeled to help the model learn them.

The researchers found that CNNs that were trained on just one of these spatial tasks showed a high level of "neuro-alignment" with the ventral stream—very similar to the levels seen in CNN models trained on object recognition.

The researchers measure neuro-alignment using a technique that DiCarlo's lab has developed, which involves asking the models, once trained, to predict the neural activity that a particular image would generate in the brain. The researchers found that the better the models performed on the spatial task they had been trained on, the more neuro-alignment they showed.

"I think we cannot assume that the ventral stream is just doing object categorization, because many of these other functions, such as spatial tasks, can also lead to this strong correlation between models' neuro-alignment and their performance," Xie says.

"Our conclusion is that you can optimize either through categorization or doing these spatial tasks, and they both give you a ventral-stream-like model, based on our current metrics to evaluate neuro-alignment."

Comparing models

The researchers then investigated why these two approaches—training for object recognition and training for spatial features—led to similar degrees of neuro-alignment. To do that, they performed an analysis known as centered kernel alignment (CKA), which allows them to measure the degree of similarity between representations in different CNNs.

This analysis showed that in the early to middle layers of the models, the representations that the models learn are nearly indistinguishable.

"In these early layers, essentially you cannot tell these models apart by just looking at their representations," Xie says. "It seems like they learn some very similar or unified representation in the early to middle layers, and in the later stages they diverge to support different tasks."

The researchers hypothesize that even when models are trained to analyze just one feature, they also take into account "non-target" features—those that they are not trained on. When

objects have greater variability in non-target features, the models tend to learn representations more similar to those learned by models trained on other tasks.

This suggests that the models are using all of the information available to them, which may result in different models coming up with similar representations, the researchers say.

"More non-target variability actually helps the model learn a better representation, instead of learning a representation that's ignorant of them," Xie says. "It's possible that the models, although they're trained on one target, are simultaneously learning other things due to the variability of these non-target features."

In future work, the researchers hope to develop new ways to compare different models, in hopes of learning more about how each one develops internal representations of objects based on differences in training tasks and training data.

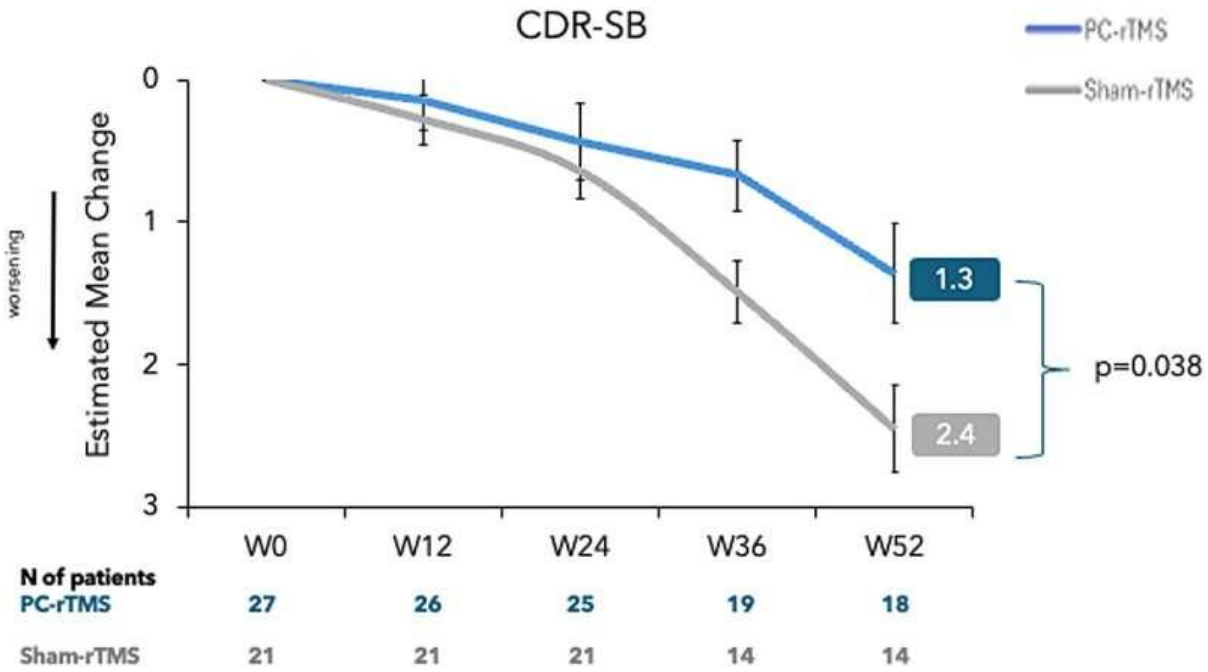
"There could still be slight differences between these models, even though our current way of measuring how similar these models are to the brain tells us they're on a very similar level. That suggests maybe there's still some work to be done to improve upon how we can compare the model to the brain, so that we can better understand what exactly the ventral stream is optimized for," Xie says.

More information: Yudi Xie et al, Vision CNNs trained to estimate spatial latents learned similar ventral-stream-aligned representations, *arXiv* (2024). DOI: 10.48550/arxiv.2412.09115
Journal information: arXiv
Provided by Massachusetts Institute of Technology

APRIL 15, 2025

Repetitive transcranial magnetic stimulation shows promise in Alzheimer's treatment

by Justin Jackson , Medical Xpress



Primary outcome measure. Estimated mean group changes for clinical scores. Credit: *Alzheimer's Research & Therapy* (2025). DOI: 10.1186/s13195-025-01709-7

Santa Lucia Foundation IRCCS-led research is reporting that repetitive transcranial magnetic stimulation (rTMS) targeting the precuneus may slow the progression of cognitive decline, impairments in daily functioning, and behavioral symptoms in patients with Alzheimer's disease. Patients who received 52 weeks of rTMS showed slower deterioration across clinical outcomes compared to those who received sham stimulation.

rTMS delivers magnetic pulses to targeted brain areas and is considered a non-invasive brain stimulation technique. It is used to treat conditions like depression and obsessive-compulsive disorder by inducing small electrical currents in brain cells to modify neural activity and help reduce symptoms.

The precuneus brain region has been identified as a promising site for stimulation due to its early involvement in Alzheimer's pathology, including amyloid deposition, gray matter loss, and disrupted connectivity within brain networks.

In animal models, rTMS has been shown to reduce beta-amyloid and phosphorylated tau, increase neurogenic proteins such as brain-derived neurotrophic factor, and decrease pro-inflammatory cytokines including IL-6 and TNF-α.

A previous Phase II trial found that 24 weeks of precuneus-targeted rTMS slowed cognitive decline and reduced loss of daily functional abilities in patients with mild-to-moderate Alzheimer's disease. Next, researchers wanted to see if extending rTMS treatment to 52 weeks could continue to preserve cognition and function over the longer time frame.

In the study, "Effects of 52 weeks of precuneus rTMS in Alzheimer's disease patients: a randomized trial," published in *Alzheimer's Research & Therapy*, researchers conducted a sham-controlled, randomized, and double-blind pilot trial.

The cohort included 48 patients diagnosed with mild-to-moderate Alzheimer's disease. A total of 27 patients were assigned to receive rTMS, and 21 were assigned to a sham stimulation group. Among them, 31 were continuing from a previous 24-week trial that used the same experimental design, and 17 were newly enrolled and randomized.

Continuing participants remained in their original treatment group and extended their participation by an additional 28 weeks, bringing their total duration of rTMS or sham exposure to 52 weeks. Newly enrolled participants began treatment at the start of the trial and completed a full 52-week course, which included a two-week intensive phase followed by weekly maintenance sessions.

Stimulation was delivered using neuronavigated transcranial magnetic stimulation paired with electroencephalography (TMS-EEG) to personalize the location and intensity for each participant. Each session involved 40 two-second trains at 20 Hz spaced over 20 minutes, totaling 96,000 pulses per patient across the trial.

Patients who received repetitive transcranial magnetic stimulation experienced a slower rate of cognitive and functional decline compared to those in the sham group. The primary outcome, measured by change in Clinical Dementia Rating Scale–Sum of Boxes, showed an estimated mean change of 1.36 points in the stimulation group compared to 2.45 points in the sham group after 52 weeks.

Functional ability, assessed using the Alzheimer's Disease Cooperative Study scale for activities of daily living, declined by an estimated 1.5 points in the rTMS group and 11.6 points in the sham group.

Cognitive performance, as measured by the Alzheimer's Disease Assessment Scale cognitive subscale, showed a mean increase of 5.9 points in the rTMS group versus 10.4 points in the sham group. In this context, higher scores reflect greater impairment.

Scores on the Mini Mental State Examination declined by 1.1 points in the rTMS group and 3.9 points in the sham group. Behavioral symptoms, measured with the Neuropsychiatric Inventory, also favored the rTMS group, with an estimated change of 3.28 points versus

6.91 points in the sham condition. Subscales showed measurable improvements in apathy, euphoria, and appetite-related disturbances.

Completion rate across both groups was 68%. Most participant withdrawals were linked to disruptions caused by the COVID-19 pandemic. Mild adverse effects such as headache or scalp discomfort were reported in both groups and resolved without medical intervention.

Stronger baseline connectivity within the brain's default mode network was associated with a more favorable clinical response in the rTMS group, suggesting that brain activity profiling could help identify patients most likely to benefit from this treatment.

Researchers concluded that rTMS targeting the precuneus may reduce the progression of cognitive decline in patients with mild-to-moderate Alzheimer's disease. The treatment also appeared to delay deterioration in daily functioning and reduce behavioral disturbances. Patients receiving rTMS did not show significant loss of autonomy over the one-year period, as measured by standardized assessments.

Some behavioral symptoms, including apathy, euphoria, and appetite-related changes, also improved in patients receiving rTMS. Fewer declines in activities of daily living may translate into lower caregiver burden and greater patient independence during early disease stages.

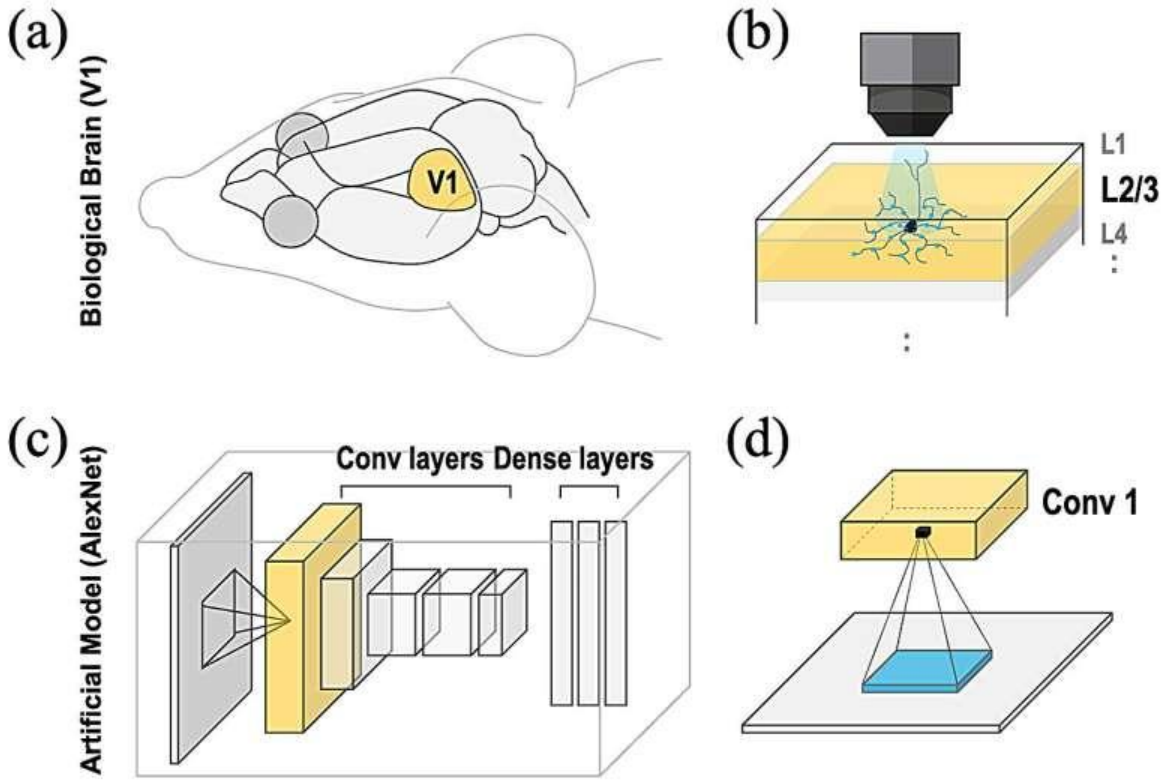
Larger studies across multiple sites are needed to confirm these findings and could also explore how rTMS could be used in combination with drug therapies that target amyloid, tau, or neuroinflammation.

More information: Giacomo Koch et al, Effects of 52 weeks of precuneus rTMS in Alzheimer's disease patients: a randomized trial, *Alzheimer's Research & Therapy* (2025). DOI: 10.1186/s13195-025-01709-7
Journal information: Alzheimer\'s Research & Therapy

APRIL 22, 2025

Brain-inspired AI technique mimics human visual processing to enhance machine vision

by Institute for Basic Science



Information processing structures of the brain's visual cortex and artificial neural networks. In the actual brain's visual cortex, neurons are connected broadly and smoothly around a central point, with connection strength varying gradually with distance (a, b). This spatial connectivity follows a bell-shaped curve known as a "Gaussian distribution," enabling the brain to integrate visual information not only from the center but also from the surrounding areas. In contrast, traditional Convolutional Neural Networks (CNNs) process information by having neurons focus on a fixed rectangular region (e.g., 3×3, 5×5, etc.) (c, d). CNN filters move across an image at regular intervals, extracting information in a uniform manner, which limits their ability to capture relationships between distant visual elements or respond selectively based on importance. This study addresses the differences between these biological structures and CNNs, proposing a new filter structure called "Lp-Convolution" that mimics the brain's connectivity patterns. In this structure, the range and sensitivity of a neuron's input are designed to naturally spread in a Gaussian-like form, allowing the system

to self-adjust during training—emphasizing important information more strongly while downplaying less relevant details. This enables image processing that is more flexible and biologically aligned compared to traditional CNNs. Credit: Institute for Basic Science
A team of researchers from the Institute for Basic Science, Yonsei University, and the Max Planck Institute have developed a new artificial intelligence (AI) technique that brings machine vision closer to how the human brain processes images. Called Lp-Convolution, this method improves the accuracy and efficiency of image recognition systems while reducing the computational burden of existing AI models.

The human brain is remarkably efficient at identifying key details in complex scenes, an ability that traditional AI systems have struggled to replicate. Convolutional Neural Networks (CNNs)—the most widely used AI model for image recognition—process images using small, square-shaped filters. While effective, this rigid approach limits their ability to capture broader patterns in fragmented data.

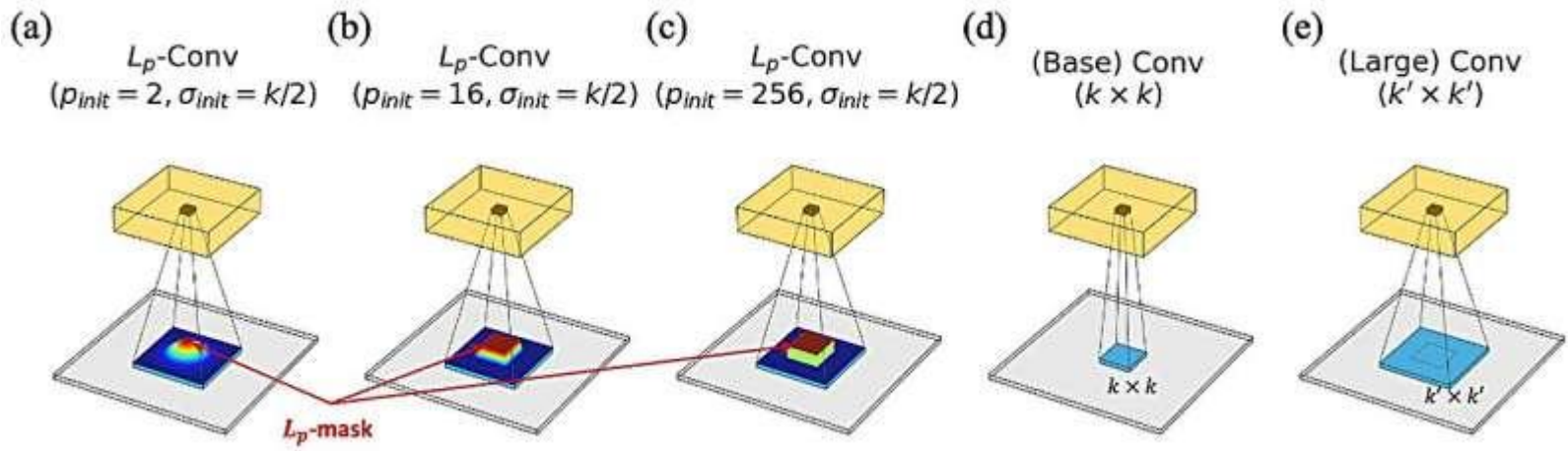
More recently, vision transformers have shown superior performance by analyzing entire images at once, but they require massive computational power and large datasets, making them impractical for many real-world applications.

Inspired by how the brain's visual cortex processes information selectively through circular, sparse connections, the research team sought a middle ground: Could a brain-like approach make CNNs both efficient and powerful?

Introducing Lp-Convolution: A smarter way to see

To answer this, the team developed Lp-Convolution, a novel method that uses a multivariate p-generalized normal distribution (MPND) to reshape CNN filters dynamically. Unlike traditional CNNs, which use fixed square filters, Lp-Convolution allows AI models to adapt their filter shapes—stretching horizontally or vertically based on the task, much like how the human brain selectively focuses on relevant details.

This breakthrough solves a long-standing challenge in AI research, known as the large kernel problem. Simply increasing filter sizes in CNNs (e.g., using 7×7 or larger kernels) usually does not improve performance, despite adding more parameters. Lp-Convolution overcomes this limitation by introducing flexible, biologically inspired connectivity patterns.



Brain-inspired design of Lp-Convolution. The brain processes visual information using a Gaussian-shaped connectivity structure that gradually spreads from the center outward, flexibly integrating a wide range of information. In contrast, traditional CNNs face issues where expanding the filter size dilutes information or reduces accuracy (d, e).To overcome these structural limitations, the research team developed Lp-Convolution, inspired by the brain's connectivity (a–c). This design spatially distributes weights to preserve key information even over large receptive fields, effectively addressing the shortcomings of conventional CNNs. Credit: Institute for Basic Science

Real-world performance: Stronger, smarter, and more robust AI

In tests on standard image classification datasets (CIFAR-100, TinyImageNet), Lp-Convolution significantly improved accuracy on both classic models like AlexNet and modern architectures like RepLKNet. The method also proved to be highly robust against corrupted data, a major challenge in real-world AI applications.

Moreover, the researchers found that when the Lp-masks used in their method resembled a Gaussian distribution, the AI's internal processing patterns closely matched biological neural activity, as confirmed through comparisons with mouse brain data.

"We humans quickly spot what matters in a crowded scene," said Dr. C. Justin Lee, Director of the Center for Cognition and Sociality within the Institute for Basic Science. "Our Lp-Convolution mimics this ability, allowing AI to flexibly focus on the most relevant parts of an image—just like the brain does."

Impact and future applications

Unlike previous efforts that either relied on small, rigid filters or required resource-heavy transformers, Lp-Convolution offers a practical, efficient alternative. This innovation could revolutionize fields such as:

- Autonomous driving, where AI must quickly detect obstacles in real time
- Medical imaging, improving AI-based diagnoses by highlighting subtle details

- Robotics, enabling smarter and more adaptable machine vision under changing conditions

"This work is a powerful contribution to both AI and neuroscience," said Director Lee. "By aligning AI more closely with the brain, we've unlocked new potential for CNNs, making them smarter, more adaptable, and more biologically realistic."

Looking ahead, the team plans to refine this technology further, exploring its applications in complex reasoning tasks such as puzzle-solving (e.g., Sudoku) and real-time image processing.

The study will be presented at the International Conference on Learning Representations (ICLR 2025), and the research team has made their code and models publicly available on GitHub and OpenReview.net.

More information: Brain-inspired Lp-Convolution benefits large kernels and aligns better with visual cortex. openreview.net/forum?id=0LSAmFCc4p
Provided by Institute for Basic Science

APRIL 21, 2025

Watching our brains remember multiple things at once

by Jeff Grabmeier, The Ohio State University

Artistic rendering of how the human brain maintains representations of multiple spatial locations in working memory. Li and his colleagues developed machine learning methods that resolve a longstanding question in neuroscience about how the brain controls memory resources. Two mountain hills symbolize the two spatial locations held in memory. Flowing rivers represent the limited neural and cognitive resources of working memory. The frontal region of the brain, depicted as the green island, controls the allocation of memory resources based on the behavioral relevance of the spatial locations held in memory. Credit: Lulu Zhang and Xinyue Hu (From Science Advances)

A new study offers insight into what is happening in our brains when our working memory must use its limited resources to remember multiple things.

Researchers found that two parts of the brain work together to ensure that more brain resources are given to remember a priority item when a person is juggling more than one item in memory.

The study involved people remembering spatial locations. Imagine seeing two books on different shelves of a cluttered bookcase that was not arranged in any order. How could you remember where they were if you came back a few seconds later?

That's the job of working memory, which temporarily stores information in your brain for a short period of time, while you process and decide what to do with it, said Hsin-Hung Li, lead author of the study and assistant professor of psychology at The Ohio State University.

In this study, published recently in the journal *Science Advances*, Li and his colleagues observed activity in the brain while people tried to remember the location of two items.

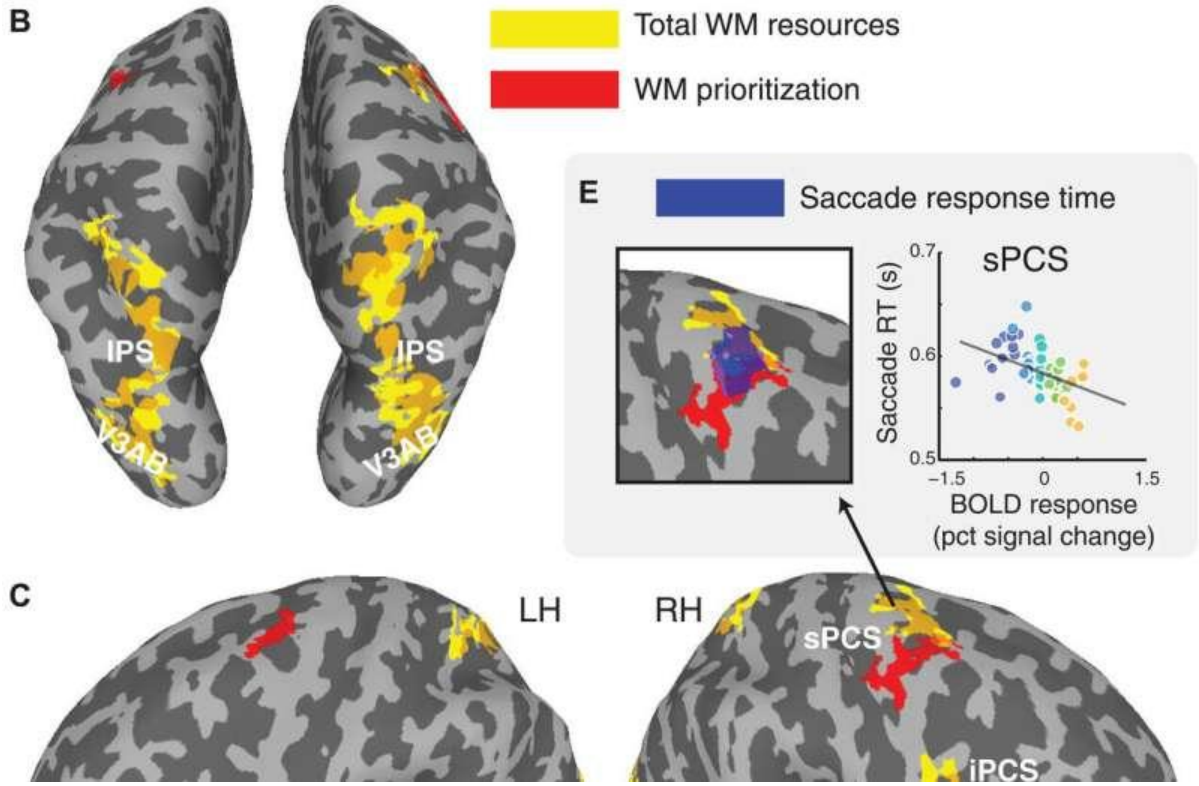
"Very often when you try to remember multiple things, one item might be more important than another," Li said.

"What we found is that the more important item is represented in the brain more precisely, while the less important item is given much lower resolution."

In the bookshelf example, you may remember exactly where on a specific shelf the more important book was located. But you may only know that the less vital book was somewhere in the upper left corner of the bookshelf.

The study involved participants whose brains were scanned in an fMRI machine while they looked at a screen. They were shown two dots, and their goal was to memorize their positions on the screen. Participants were told it was more important to remember the location of the dot that appeared in one area of the screen—this was the high-priority item.

The two dots appeared on the screen simultaneously for just a half-second. Twelve seconds later the participants were asked where one of the dots had appeared. Usually, they were asked where the high-priority dot had appeared. But about 30% of the time, they were asked to indicate where the low-priority dot had shown up.



Delay period activity in higher-order cortical areas predicts the quality of decoded WM representations. Credit: *Science Advances* (2025). DOI: 10.1126/sciadv.adr8015

Researchers found that they could see activity in the visual cortex of the brain as the participants tried to memorize the location of the dots, Li said. The high-priority dot was represented more precisely, while the low-priority dot was represented more coarsely, with less resolution.

This tactic by the brain worked. Later, when participants indicated where they had seen the dots on the screen, they placed the high-priority dot closer to its actual location than they did with the low-priority dot.

The researchers found something else when they analyzed the fMRI scans—the frontal cortex of the brain was communicating with the visual cortex, telling it the level of resources it should allocate to remembering the location of each dot.

"With limited memory resources, the frontal cortex was deciding which dot would get more resources, so it would be remembered more precisely," Li said.

This finding was important because neuroscientists had debated which part of the brain—the frontal cortex or the visual cortex—is responsible for working memory involving visual objects, like the dots in this study.

"We found that they both had a role. The visual cortex creates the visual representation of the two dots that people were trying to remember," he said.

"But the frontal cortex is making this allocation decision about which one should get more working memory resources and which one should get less."

Another unique part of this study was the fact the researchers decoded brain activity of people looking at two different things at once for each single trial, something that has rarely been done.

"It is a very useful technique, and I think scientists will use this more in the future. There are so many situations in which people are trying to hold multiple thoughts in their minds and it is very useful to be able decode more than one," Li said.

Li did the research at New York University, where he received his Ph.D. and was a postdoctoral researcher. Other co-authors on the study were Thomas Sprague, a former NYU postdoctoral fellow now at the University of California, Santa Barara; and Aspen Yoo, Wei Ji Ma and Clayton Curtis of NYU.

More information: Hsin-Hung Li et al, Neural mechanisms of resource allocation in working memory, *Science Advances* (2025). DOI: 10.1126/sciadv.adr8015
Journal information: Science Advances
Provided by The Ohio State University

APRIL 21, 2025

Brain scans reveal neural circuitry linked with the subjective interpretation of art

by Columbia University

Credit: Columbia University

These paintings are both by the Dutch artist Piet Mondrian but display strikingly different styles. The house on the left is representational; the colorful squares on the right are more abstract. In a new study published in the *Proceedings of the National Academy of Sciences*, scientists showed this pair of paintings (and others) to people while scanning their brains. The results shed light on how we respond to art and provide a scientific test of a longstanding idea in art theory.

Researchers at Columbia's Zuckerman Institute found that people's brain activity varied more when viewing abstract art, as compared with representational art. This was especially true in the default mode network, a brain region linked to interpreting the meanings underlying narratives, as well as abstract thought, imagination and creativity.

"These findings support the idea that observers are more likely to analyze abstract art in their own uniquely personal way," said Celia Durkin, Ph.D., first author on the new study and a former graduate student in the Shohamy lab.

The discovery is a step toward fulfilling a longstanding goal of Nobel laureate and study co-author Eric Kandel, MD: to understand how the brain contributes to the experience of art.

"Eric approached me with an interest in developing a test of 'the beholder's share,' a concept from art history that suggests observers actively engage in constructing meaning as they view art," said study co-author Daphna Shohamy, Ph.D., director and CEO of Columbia's Zuckerman Institute.

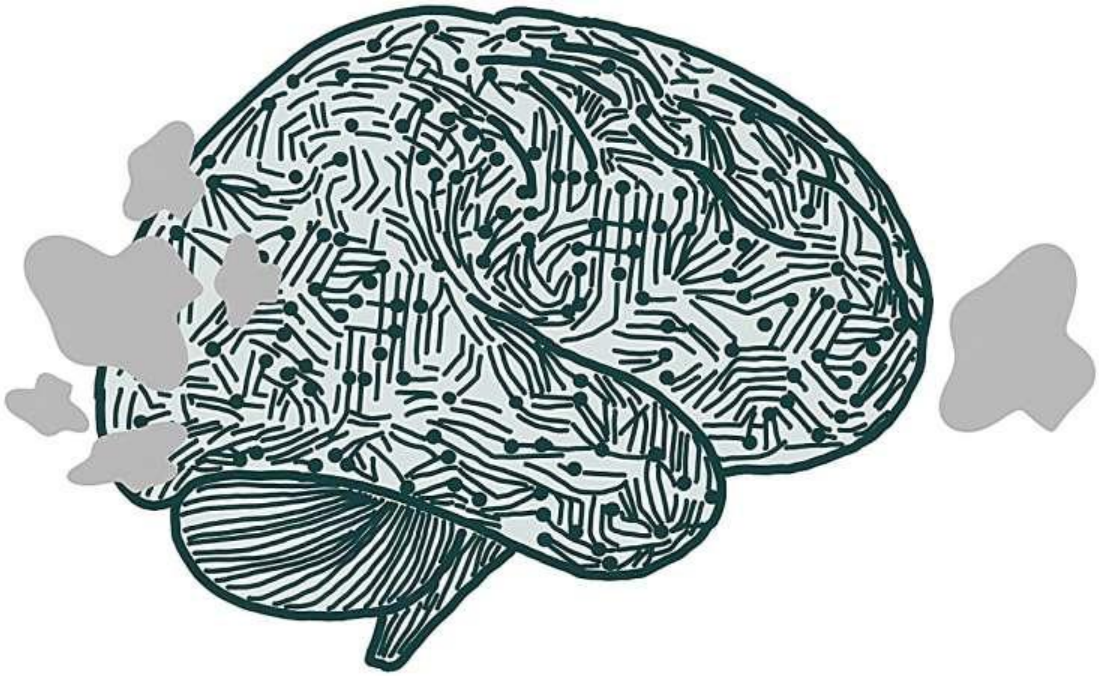
"The experiment provides scientific evidence that viewing and interpreting abstract art relies on personal experiences and memories, not just in theory, but in patterns of brain activity."

More information: Celia Durkin et al, The Beholder's Share: Bridging art and neuroscience to study individual differences in subjective experience, *Proceedings of the National Academy of Sciences* (2025). DOI: 10.1073/pnas.2413871122
Journal information: Proceedings of the National Academy of Sciences
Provided by Columbia University

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.

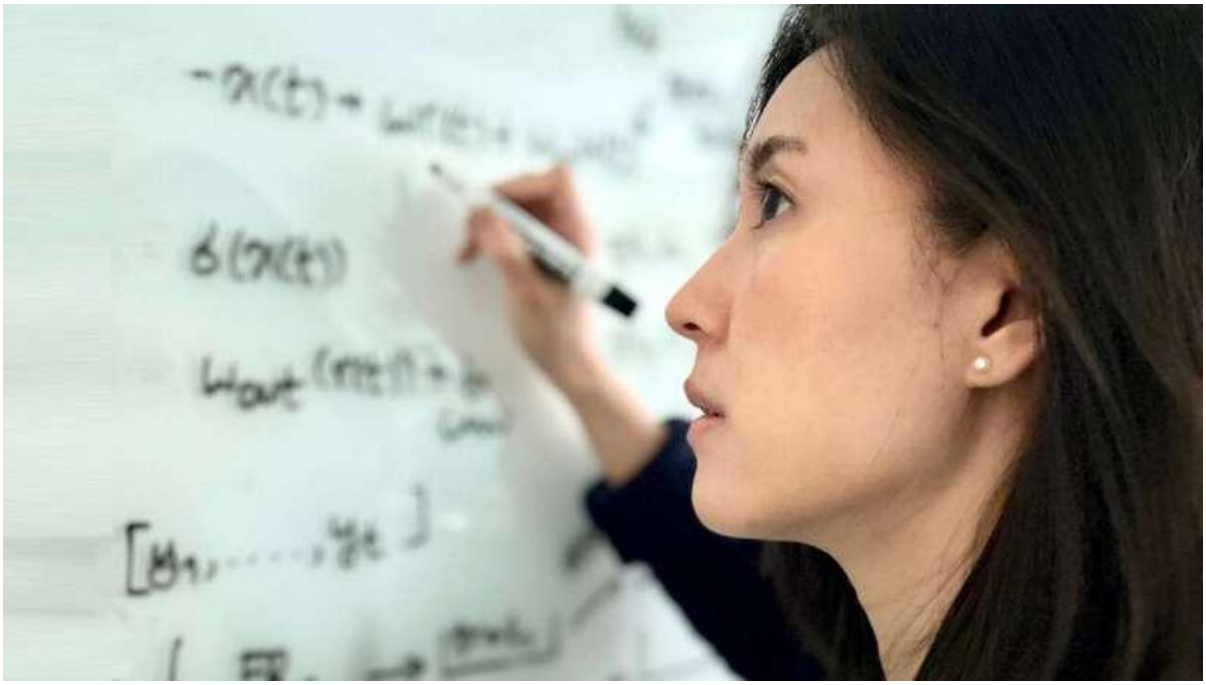
We sat down with Rungratsameetaweemana to learn more about the research.

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

APRIL 15, 2025

Mapping study pinpoints key brain regions for reasoning skills

by University College London

A team of researchers at UCL and UCLH have identified the key brain regions that are essential for logical thinking and problem solving.

The findings, published in *Brain,* help to increase our understanding of how the human brain supports our ability to comprehend, draw conclusions, and deal with new and novel problems—otherwise known as reasoning skills.

To determine which brain areas are necessary for a certain ability, researchers study patients with brain lesions (an area of damage in the brain) caused by stroke or brain tumors. This approach, known as "lesion-deficit mapping," is the most powerful method for localizing function in the human brain.

Studying brain injuries can be difficult and time-consuming because researchers need a large number of patients with specific brain damage. This kind of damage can affect how a person thinks, feels, or moves. However, very few research centers have access to enough patients to conduct these studies effectively.

As a result, previous studies have mainly relied on functional imaging (fMRI) techniques in healthy individuals. However, these results can sometimes be misleading as they provide correlational rather than causal evidence.

The new study, led by researchers at the UCL Queen Square Institute of Neurology and Department of Neuropsychology at the National Hospital for Neurology and Neurosurgery, UCLH, used lesion-deficit mapping to investigate 247 patients with unilateral focal brain lesions in either the left or right frontal (front) or posterior (back) regions of the brain. An additional 81 healthy individuals served as controls.

To assess reasoning skills in these patients, the researchers developed two new tests.

These included a verbal analogical reasoning task (a type of puzzle where participants are asked to find relationships between words to solve problems), which included questions such as: "If Sarah is smarter than Diana and Sarah is smarter than Heather, is Diane smarter than Heather?".

And a nonverbal deductive reasoning task (a type of puzzle where participants are asked to use pictures, shapes or numbers to figure out logical patterns and solve problems), with questions like: "Which set of numbers is 1,2,3 most similar to—5,6,7 or 6,5,7?".

The results showed that people with damage to the right frontal lobe had a much harder time on both tests compared to those with damage in other areas. They made about 15% more mistakes than the other patients and healthy individuals.

Lead author, Dr. Joseph Mole (UCL Queen Square Institute of Neurology and Department of Neuropsychology, UCLH) said, "Our study explores how the front right part of the brain helps people think and solve new problems.

"It also shows that our two new tests can help detect reasoning problems in individuals with brain damage, improving diagnosis and treatment."

Senior author, Professor Lisa Cipolotti (UCL Queen Square Institute of Neurology and Department of Neuropsychology, UCLH) added, "By combining a detailed cognitive investigation in a large sample of brain damaged patients with advanced lesion mapping techniques—developed by Professor Parashkev Nachev and his team at the UCL Queen Square Institute of Neurology—we have deepened our understanding of the complex and, so far, poorly understood, neural structures underlying human reasoning.

"Our findings show a close connection between the right frontal brain network involved in reasoning and the right frontal brain network essential for fluid intelligence (our ability to solve problems without prior experience). This suggests that a common area of the brain plays a critical role in both reasoning and fluid intelligence."

The researchers believe that these findings have significant clinical implications, as the two new tests can help identify cognitive impairments that would otherwise go undetected.

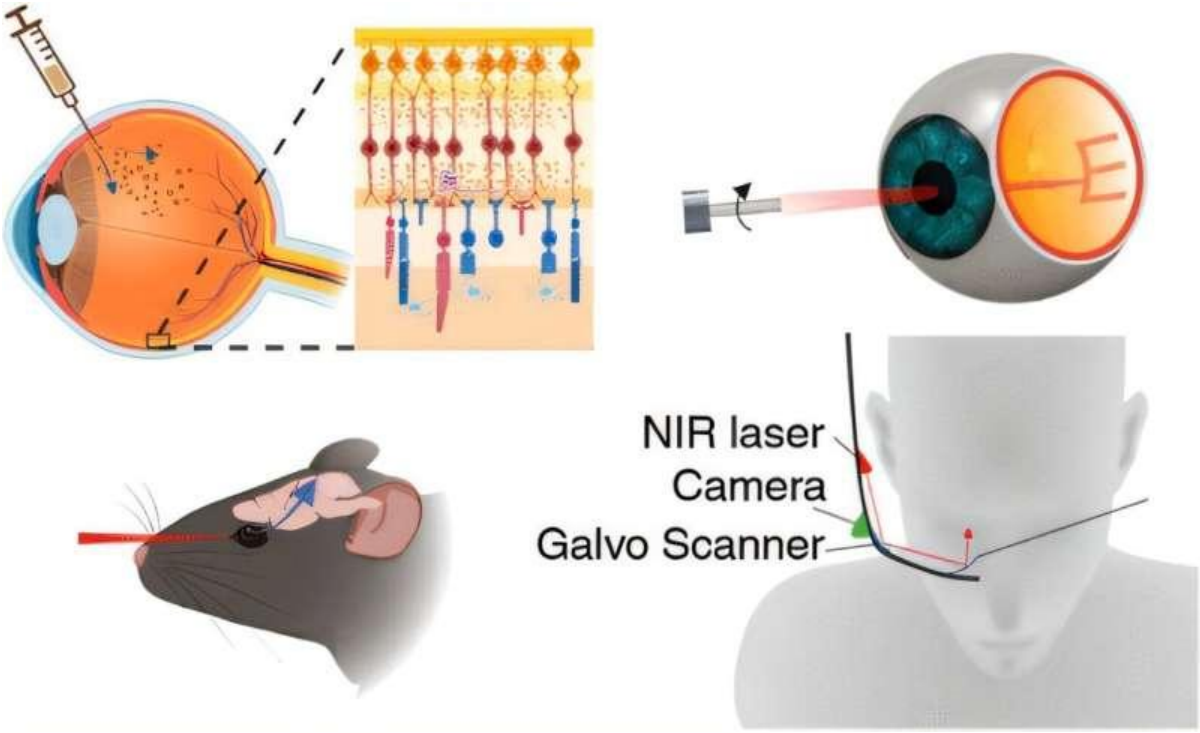
With further validation and implementation, the team aim to make their new reasoning tests widely available in the NHS, addressing an unmet need for tools specifically designed for assessing right frontal lobe dysfunction.

More information: A right frontal network for analogical and deductive reasoning, *Brain* (2025). dx.doi.org/10.1093/brain/awaf062
Journal information: Brain
Provided by University College London

APRIL 16, 2025

Golden eyes: How gold nanoparticles may one day help to restore people's vision

by Kevin Stacey, Brown University



Credit: *ACS Nano* (2025). DOI: 10.1021/acsnano.4c14061

A new study by Brown University researchers suggests that gold nanoparticles—microscopic bits of gold thousands of times thinner than a human hair—might one day be used to help restore vision in people with macular degeneration and other retinal disorders.

In a study published in the journal *ACS Nano*, the research team showed that nanoparticles injected into the retina can successfully stimulate the visual system and restore vision in mice with retinal disorders. The findings suggest that a new type of visual prosthesis system in which nanoparticles, used in combination with a small laser device worn in a pair of glasses or goggles, might one day help people with retinal disorders to see again.

"This is a new type of retinal prosthesis that has the potential to restore vision lost to retinal degeneration without requiring any kind of complicated surgery or genetic modification," said Jiarui Nie, a postdoctoral researcher at the National Institutes of Health who led the

research while completing her Ph.D. at Brown. "We believe this technique could potentially transform treatment paradigms for retinal degenerative conditions."

Nie performed the work while working in the lab of Jonghwan Lee, an associate professor in Brown's School of Engineering and a faculty affiliate at Brown's Carney Institute for Brain Science, who oversaw the work and served as the study's senior author.

Retinal disorders like macular degeneration and retinitis pigmentosa affect millions of people in the U.S. and around the world. These conditions damage light-sensitive cells in the retina called photoreceptors—the "rods" and "cones" that convert light into tiny electric pulses. Those pulses stimulate other types of cells further up the visual chain called bipolar and ganglion cells, which process the photoreceptor signals and send them along to the brain.

This new approach uses nanoparticles injected directly into the retina to bypass damaged photoreceptors. When infrared light is focused on the nanoparticles, they generate a tiny amount of heat that activates bipolar and ganglion cells in much the same way that photoreceptor pulses do. Because disorders like macular degeneration affect mostly photoreceptors while leaving bipolar and ganglion cells intact, the strategy has the potential to restore lost vision.

In this new study, the research team tested the nanoparticle approach in mouse retinas and in living mice with retinal disorders. After injecting a liquid nanoparticle solution, the researchers used patterned near-infrared laser light to project shapes onto the retinas. Using a calcium signal to detect cellular activity, the team confirmed that the nanoparticles were exciting bipolar and ganglion cells in patterns matched the shapes projected by the laser.

The experiments showed that neither the nanoparticle solution nor the laser stimulation caused detectable adverse side effects, as indicated by metabolic markers for inflammation and toxicity. Using probes, the researchers confirmed that laser stimulation of the nanoparticles caused increased activity in the visual cortices of the mice—an indication that previously absent visual signals were being transmitted and processed by the brain. That, the researchers say, is a sign that vision had been at least partially restored, a good sign for potentially translating a similar technology to humans.

For human use, the researchers envision a system that combines the nanoparticles with a laser system mounted in a pair of glasses or goggles. Cameras in the goggles would gather image data from the outside world and use it to drive the patterning of an infrared laser. The laser pulses would then stimulate the nanoparticles in people's retinas, enabling them to see.

The approach is similar to one that was approved by the Food and Drug Administration for human use a few years ago. The older approach combined a camera system with a small

electrode array that was surgically implanted in the eye. The nanoparticle approach has several key advantages, according to Nie.

For starters, it's far less invasive. As opposed to surgery, "an intravitreal injection is one of the simplest procedures in ophthalmology," Nie said.

There are functional advantages as well. The resolution of the previous approach was limited by the size of the electrode array—about 60 square pixels. Because the nanoparticle solution covers the whole retina, the new approach could potentially cover someone's full field of vision. And because the nanoparticles respond to near-infrared light as opposed to visual light, the system doesn't necessarily interfere with any residual vision a person may retain.

More work must be done before the approach can be tried in a clinical setting, Nie said, but this early research suggests that it's possible.

"We showed that the nanoparticles can stay in the retina for months with no major toxicity," Nie said of the research. "And we showed that they can successfully stimulate the visual system. That's very encouraging for future applications."

More information: Jiarui Nie et al, Intravitreally Injected Plasmonic Nanorods Activate Bipolar Cells with Patterned Near-Infrared Laser Projection, *ACS Nano* (2025). DOI: 10.1021/acsnano.4c14061
Journal information: ACS Nano
Provided by Brown University

Neuroscience discoveries: 5 new studies offer unexpected insights into the brain

The human brain is constantly responding to its environment, storing memories, learning new skills, and navigating complex social and emotional experiences. But what exactly influences the way our brains develop, adapt, or decline? A growing body of research is shedding light on the forces that shape our neural circuitry—ranging from the music we love to the air we breathe. Below are five recently published neuroscience studies that uncover surprising insights into how the brain works.

1. Air pollution may trigger memory loss by disrupting brain proteins

New research published in *Proceedings of the National Academy of Sciences* shows how breathing polluted air can damage the brain. The study focused on a chemical process called S-nitrosylation, which can be triggered by inflammation and environmental toxins like smog or wildfire smoke. Scientists found that this process alters a key brain protein called CRTC1, which normally helps activate genes necessary for learning and memory. When CRTC1 is modified by S-nitrosylation, it can no longer interact properly with another

important protein called CREB, disrupting gene expression and harming memory-related brain functions.

In experiments using brain cells, mouse models of Alzheimer's disease, and human nerve cells derived from patients, the researchers found that blocking this chemical change improved brain cell function and even reversed some memory problems. This suggests that pollution-related brain damage may be reversible—and that targeting S-nitrosylation could be a promising treatment strategy for neurodegenerative diseases. The research highlights a direct biological link between environmental toxins and conditions like Alzheimer's, opening the door to preventive and therapeutic approaches that go beyond the lungs and heart to protect the brain.

2. Nostalgic music activates memory and emotion networks in the brain

A study published in *Human Brain Mapping* found that nostalgic songs uniquely engage brain areas related to memory, self-reflection, and emotion. Participants who listened to personally meaningful songs from their past showed greater activation in regions like the hippocampus, medial prefrontal cortex, and anterior insula—areas involved in retrieving autobiographical memories and processing emotions. Older adults in the study showed especially strong responses to nostalgic music, suggesting that these songs may play a powerful role in emotional regulation and memory preservation as we age.

The researchers carefully compared nostalgic music to musically similar—but emotionally neutral—songs to ensure that the effects were driven by memory and personal meaning rather than tempo or familiarity. Brain scans revealed that nostalgic music not only activated more areas overall but also enhanced connectivity between regions involved in self-awareness and emotional salience. These findings support the use of personalized music in therapeutic settings, especially for individuals with dementia, and point to a biologically grounded explanation for why music can evoke vivid memories and feelings from long ago.

3. Left- and right-wing authoritarianism linked to different brain structures

A new study in *Neuroscience* suggests that people who hold authoritarian views—regardless of political leaning—may have distinct brain differences. The research found that young adults with strong right-wing authoritarian beliefs had smaller gray matter volume in the dorsomedial prefrontal cortex, a region involved in perspective-taking and moral reasoning. In contrast, those with high scores on left-wing authoritarianism, particularly aggressive anti-authority views, had thinner cortex in the right anterior insula, a region tied to empathy and emotional regulation.

These brain differences were associated with behavioral traits often linked to authoritarianism, such as impulsivity and anxiety. The study also found that right-wing authoritarians were more likely to endorse social dominance, while left-wing authoritarians aligned with more radical anti-establishment views. Though the research is limited by its cross-sectional design and homogenous sample, it opens a new line of inquiry into how structural brain differences might interact with emotional tendencies and social environments to shape political beliefs. The authors emphasize that brain anatomy does not cause ideology but may reflect long-term patterns of thought and behavior.

4. Neurons use multiple “learning rules” to store new information

In a study published in *Science*, researchers uncovered a surprising detail about how the brain learns: neurons don’t follow just one rule for changing their connections—they follow several at once. Using real-time imaging in mice, scientists found that synapses (the junctions between neurons) on different parts of the same neuron followed different rules for learning. Some synapses strengthened their connections when neurons fired together, as predicted by the classic “fire together, wire together” rule. But others followed entirely different patterns, responding independently of the neuron’s own firing.

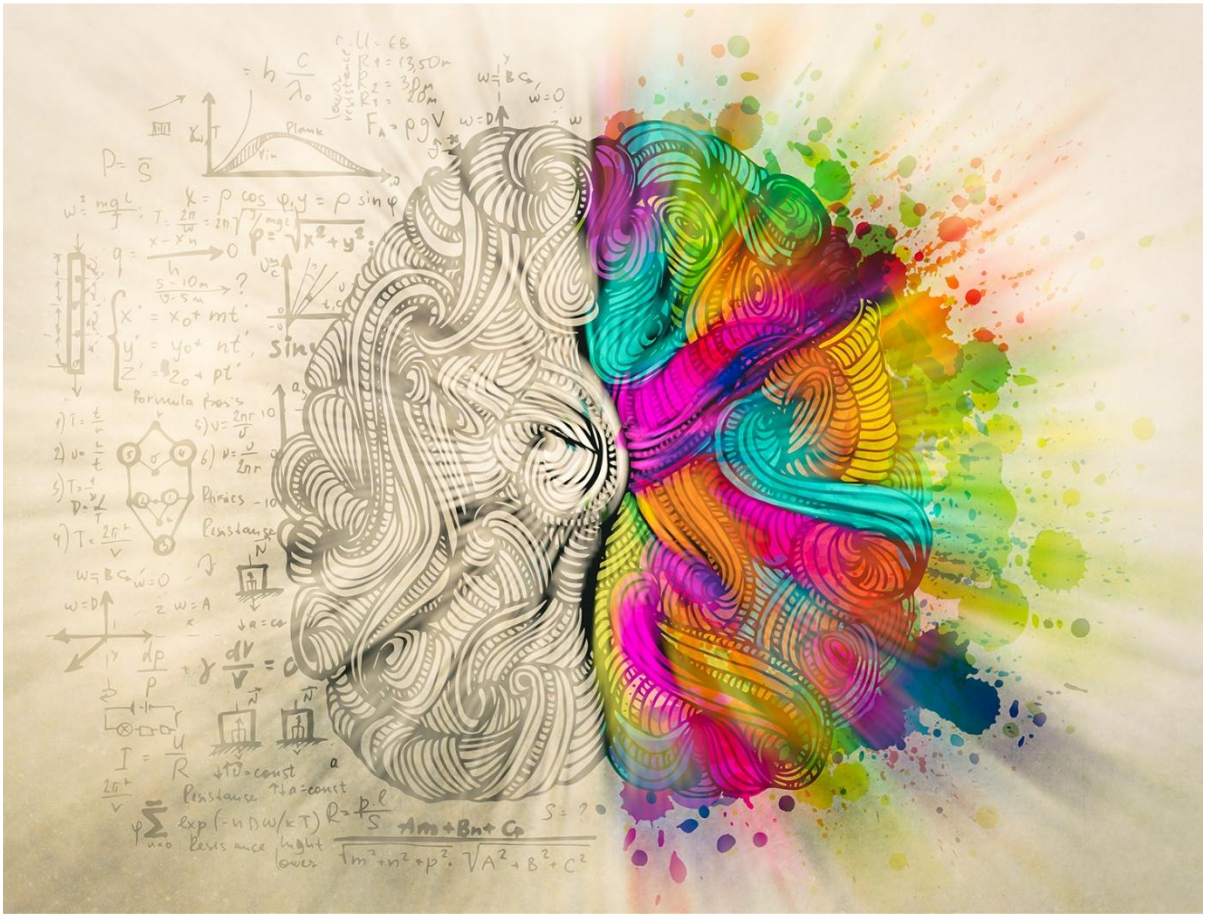
This discovery offers a new explanation for how the brain efficiently encodes complex information. By applying different learning rules across different synapses, a single neuron can process multiple types of input at once, helping the brain multitask and adapt to new experiences. The findings could have implications for artificial intelligence and mental health. For example, understanding these flexible learning mechanisms may improve treatments for conditions like depression, which involve disruptions in synaptic plasticity, and inspire more biologically realistic models of learning in AI systems.

5. Children’s brains respond differently to books than to screens

A study in *Developmental Science* found that preschool children’s brains show distinct activity patterns when being read to from a book versus watching a story on a screen. During live book reading, children showed greater activation in the right hemisphere, especially in the temporal parietal junction—a region involved in social understanding and shared attention. In contrast, screen-based storytelling produced more balanced activity across both brain hemispheres, suggesting a different kind of engagement.

The study involved 3- to 6-year-old children who experienced both types of storytelling while their brain activity was measured using near-infrared imaging. Despite the screen stories having the same content and language as the live readings, the presence of a real person reading aloud appeared to make a difference in how the brain processed the experience. These findings suggest that the social interaction involved in live book reading may help build neural pathways important for communication and empathy. While the study had a small, homogenous sample, it adds to a growing body of evidence suggesting that not all storytime experiences are equal in their effects on early brain development.

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”.

Apple Focusing on Smart Glasses which Might Replace iPhone: Reports

Even though Apple's massive fame for its product lineups is margined to infinity, the Cupertino tech conglomerate is promptly in need of variety. The last time this tech world witnessed Apple releasing new product was the iPad which despite being an inarguable success proved difficult to maintain its momentum. Augmented reality, being a new and exciting platform, wouldn't be of a huge competition (at least as of present) for Apple. Hence Apple working on something massive with AR software is very much a possibility.

Things get clearer with the latest report which has been subjected to Apple's potential replacement for its flag bearer, the iPhone. Apple's smart glasses have been longly rumored device anticipated to come with the augmented reality feature. The standalone AR device has had its fair share of leaks and anticipations in the recent past. But the latest report indicates that the alleged Apple Glass would be nothing unlike the regular pair of glasses with the design kept simple and stylish. What's great, years ago Google's AR glass saw the light of the day but was failed to impress fans due to the looking design. With the simple smart glass, Apple is apparently set to leave no stones unturned.

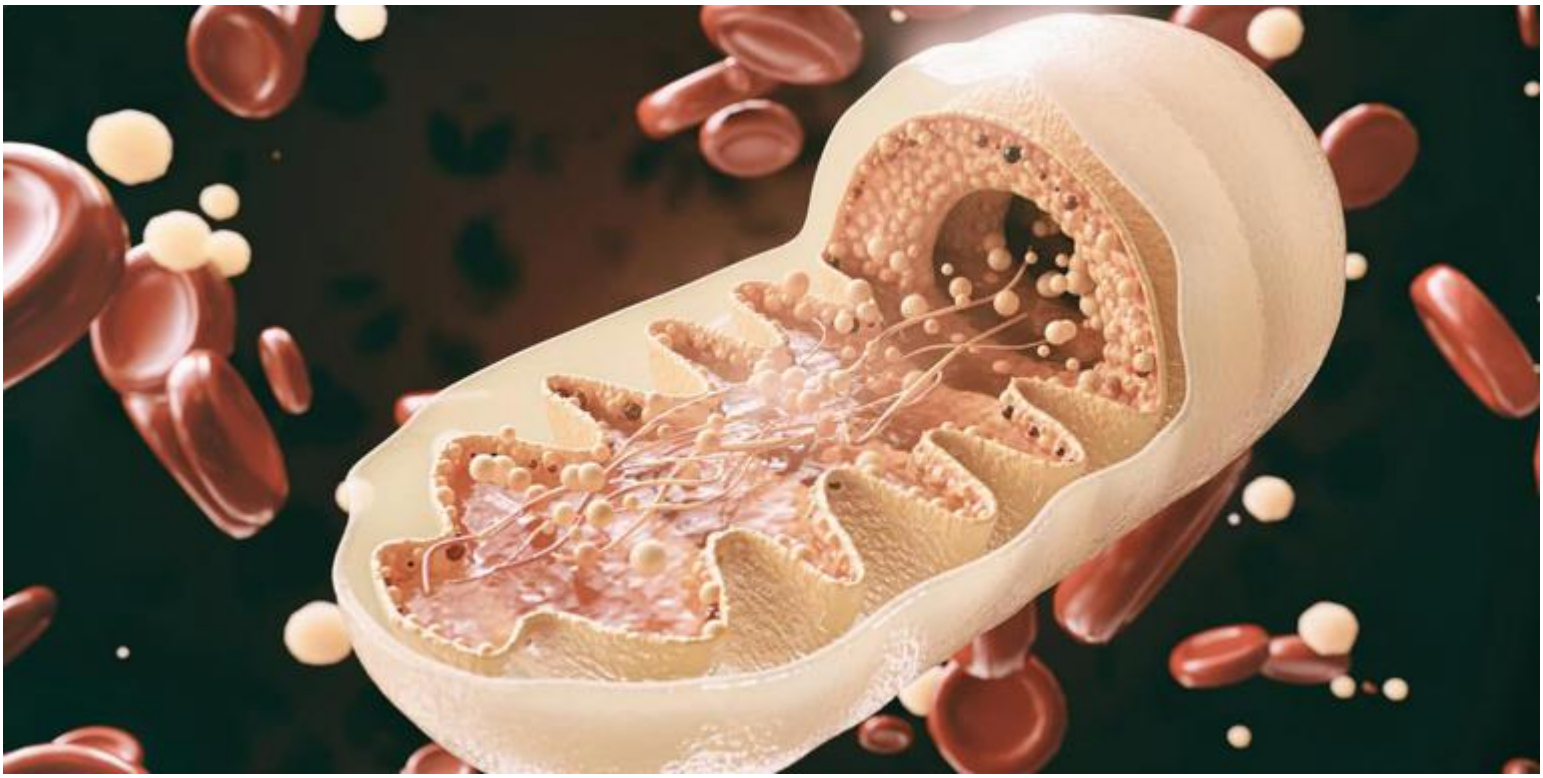
Alleged Apple Glasses Might Replace iPhones in Near Future [Image Source]

In terms of design, Apple's smart glass will likely be manufactured with high-end metal. The frame might have a slew of cameras, reports Gizbot. In addition, there would be wireless antennas which will enable users to use this particular Apple device as an alternative to their smartphones. So in a way, we are plausibly approaching the world of smart glasses, the potential replacement for smartphones (iPhones).

Little do we know that like the iPhone X's controversial 'notch', this Apple glasses might house the camera as well as one of the ambient sensors. The sides of the device will be occupied with Bluetooth and Wi-Fi components. Also, like the iPhone, this smart glasses is believed to come with split antenna design. Fabricated will be the arms of the glasses which will bestow a comfortable design. With the inclusion of Siri, Apple's glasses will also sport display maps, videos as well as texts.

While the glasses are expected to be sans the power port, wireless charging is the ultimate mode to fuel it accordingly. Despite Apple refusing to confirm the existence of smart glasses publicly, reports already shed lights that the Cupertino tech giant is developing an AR-based device via Tim Cook's speech, and we already know that it apparently will happen and, "it will happen in a big way, and we will wonder when it does, how we ever lived without it. Like we wonder how we lived without our phone today."

First-ever brain mitochondria map reveals energy secrets of the mind



[Adobe Stock]© PsyPost

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.

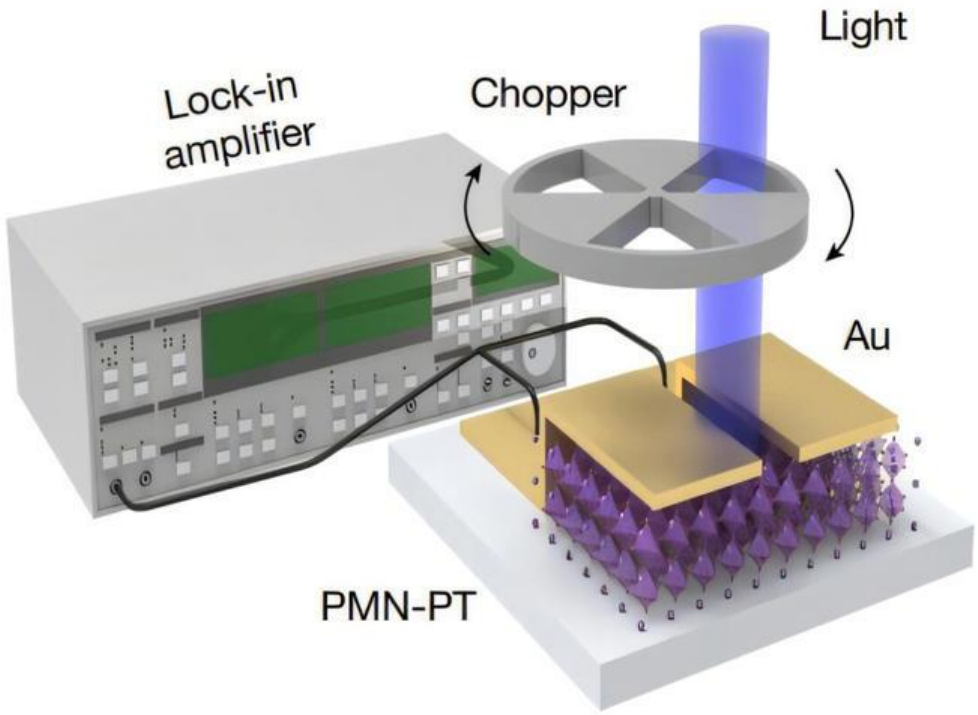
"A major limitation of our study is that our model and conclusions are based on data from a single brain," Thiebaut de Schotten noted. "While this provides valuable initial insights, studying more brains to understand how mitochondrial patterns vary across individuals is essential. Securing funding for 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.

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.

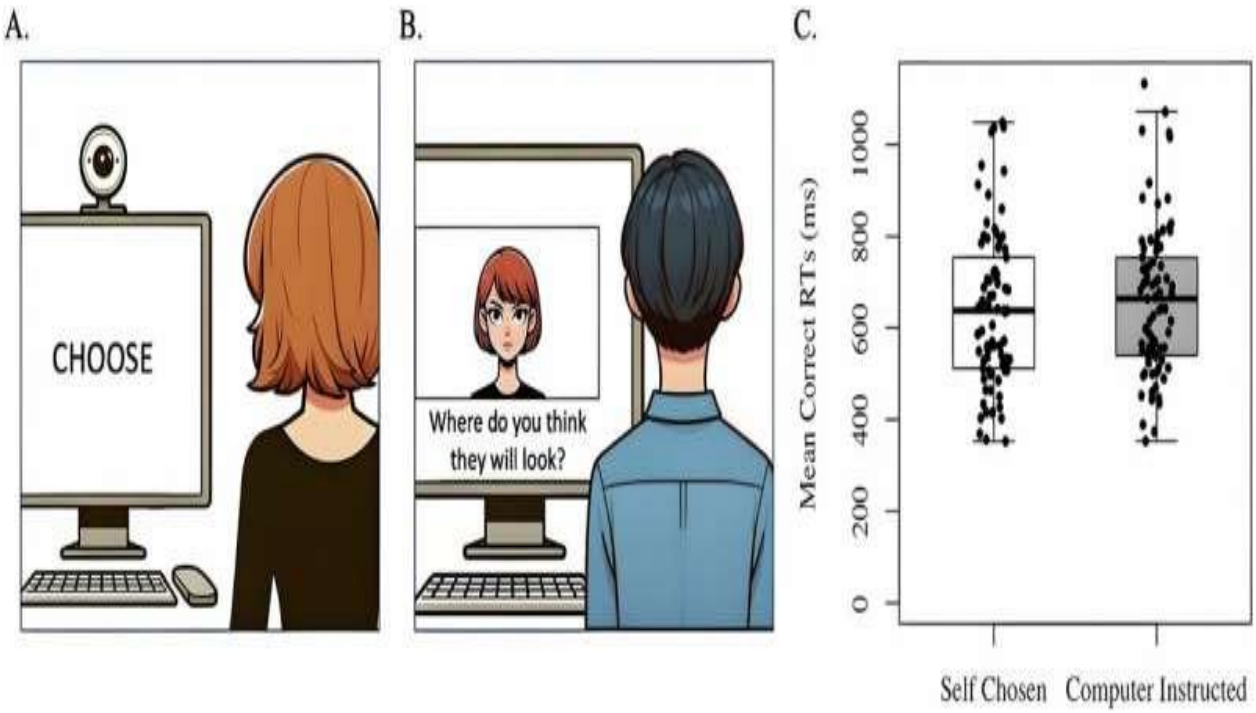
"To turn this into a night-vision system, a functional device array should be integrated with readout circuitry. Furthermore, testing in varied environmental conditions is essential for practical applications."

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

APRIL 23, 2025

Our brains can communicate wordlessly, through our eyes

by Katherine Gombay, McGill University



Experiment 1 design and results. **A** Example instruction display for the gazers. Gazers sat in front of a computer screen at an approximate distance of 60 cm with their face and torso filmed using a camera centered on top of the screen. They first saw an instruction for 4000 ms informing them how they should direct their eyes by displaying either 'Choose' or 'Left/Right' message. Next, a peripheral placeholder dot was presented on each left and right side of fixation, and the gazers were instructed to look towards and remain looking at a chosen or instructed location dot for an additional 4000 ms. **B** Example response display for observers. Observers viewed a clip of the gazer making eye movements. The gazer first looked straight ahead for 2000 ms and at T_0 started their eye movement, at which point the video was paused. Observers responded by indicating the direction (left or right) of the gazer's upcoming eye movement. **C** Experiment 1 results. Box plot showing Median Response Time (RT; solid horizontal line) as a function of Gaze intentionality (Self-chosen gaze vs. Computer-instructed gaze; $N = 81$ participants). Boxes encompass data points between the 25th and 75th percentiles, with whiskers indicating the larger minimum value and the smaller maximum value. Points represent individual participant's data.
Credit: *Communications Psychology* (2024). DOI: 10.1038/s44271-024-00137-x

McGill researchers have demonstrated something long assumed: that glances can transmit information about one's mental state to others without a single word being exchanged. They speculate that this primal ability may have played a role in assuring the survival of human society at times when making a sound could have attracted predators.

The research is published in the journal *Communications Psychology*.

"Humans have a long history of living in complex groups and social situations. It has been theorized that this has led our brains to develop a heightened ability to focus on social cues from faces, and especially from eyes," said Jelena Ristic, a professor in McGill's psychology department. She has been working in the field for over 20 years. "It's a system that has evolved to support very quick exchanges of complex social information."

"Gaze-following is thought to provide a foundation for our social development and behavior. It helps us to understand what others are thinking, looking or wanting, as well as to connect with them mentally, so we follow where others are looking quickly and spontaneously. Even young human infants and primates do it," she said.

Able to glean intentions by looking at eyes

Ristic is the senior author of the research paper describing a series of seemingly simple experiments in which participants viewed videos in which people on screen looked either right or left. Sometimes the subjects on screen had been instructed to look in one direction or the other, and other times they were allowed to choose where to look. Videos were paused just before the subjects moved their eyes, and the observers were asked to predict the direction that the subjects were going to look next.

The researchers discovered that when the people on screen were free to choose the direction of their gaze—what the researchers called "intentional looks"—the observers' rate of accuracy was not affected. However, those who predicted correctly were able to do so more quickly.

In other words, the observers were able to glean intentions in the eyes before any action had taken place.

"The speed of the observers' responses suggests that they implicitly recognize and respond more quickly to intentional eye movements. It also told us how sensitive we are to information about the mental state and intentions conveyed by the eyes," said Florence Mayrand, a Ph.D. candidate in the Department of Psychology and the paper's first author.

Characteristics of eye movements may provide clues about intentions

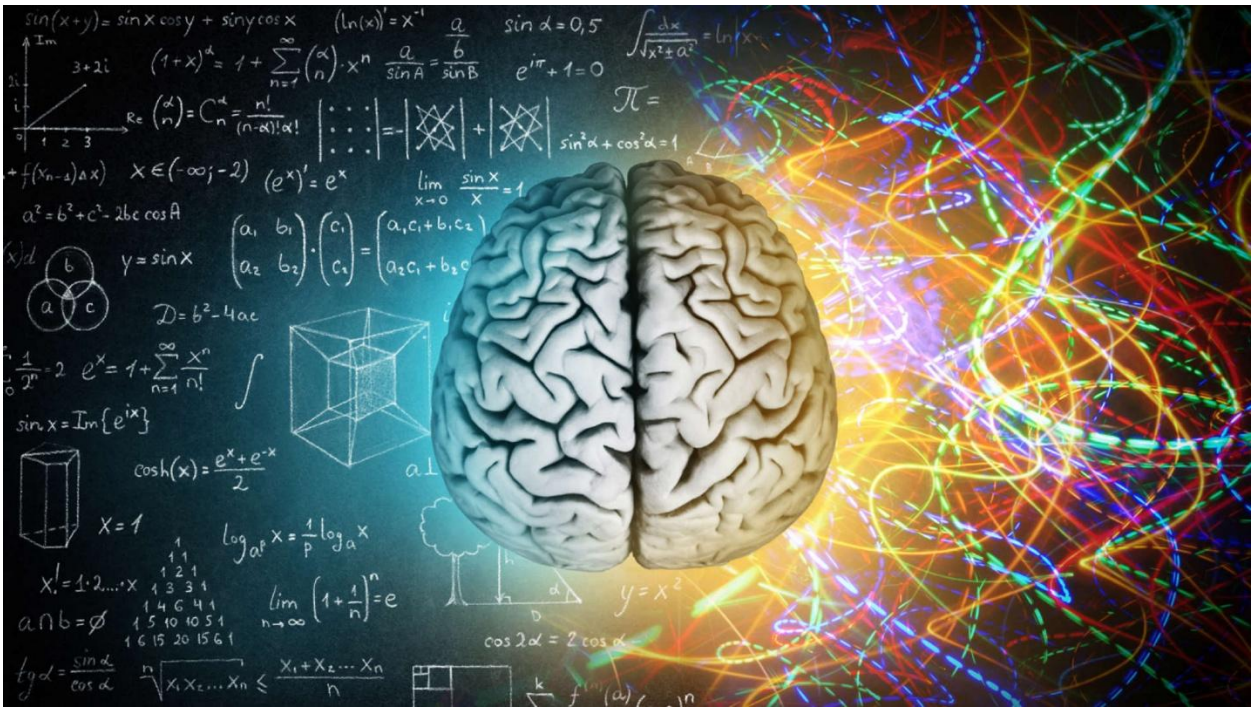
To try to understand why observers were able to guess eye-shift direction more quickly when people on screen had been left free to choose the direction in which they would look,

the researchers analyzed the amount of motion available in the eye movement video. More movement was found in the area near the eyes right before the gaze shift, when the gazers could choose freely where to look, than when they had been told which way to look. This suggested to the investigators that intentional looks are marked by specific movement patterns.

To further understand whether intentional looks have any special physical properties to which people are inherently sensitive, the researchers are currently measuring the speed, trajectory, duration and the number of blinks and blink characteristics for intentional and directed looks in a new sample of study participants.

Following this, they plan to examine whether these fundamental properties differ according to the intentions of the person looking in one direction or the other; for example, whether they are intending to deceive or help; how the ability to read intentions from eye gaze develops; what the underlying brain mechanisms are; and whether there are any differences in sensitivity to intentions in gaze for groups with social difficulties, such as adults or children with autism or ADHD.

More information: Florence Mayrand et al, Intentional looks facilitate faster responding in observers, *Communications Psychology* (2024). DOI: 10.1038/s44271-024-00137-x
Journal information: Communications Psychology
Provided by McGill University



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.

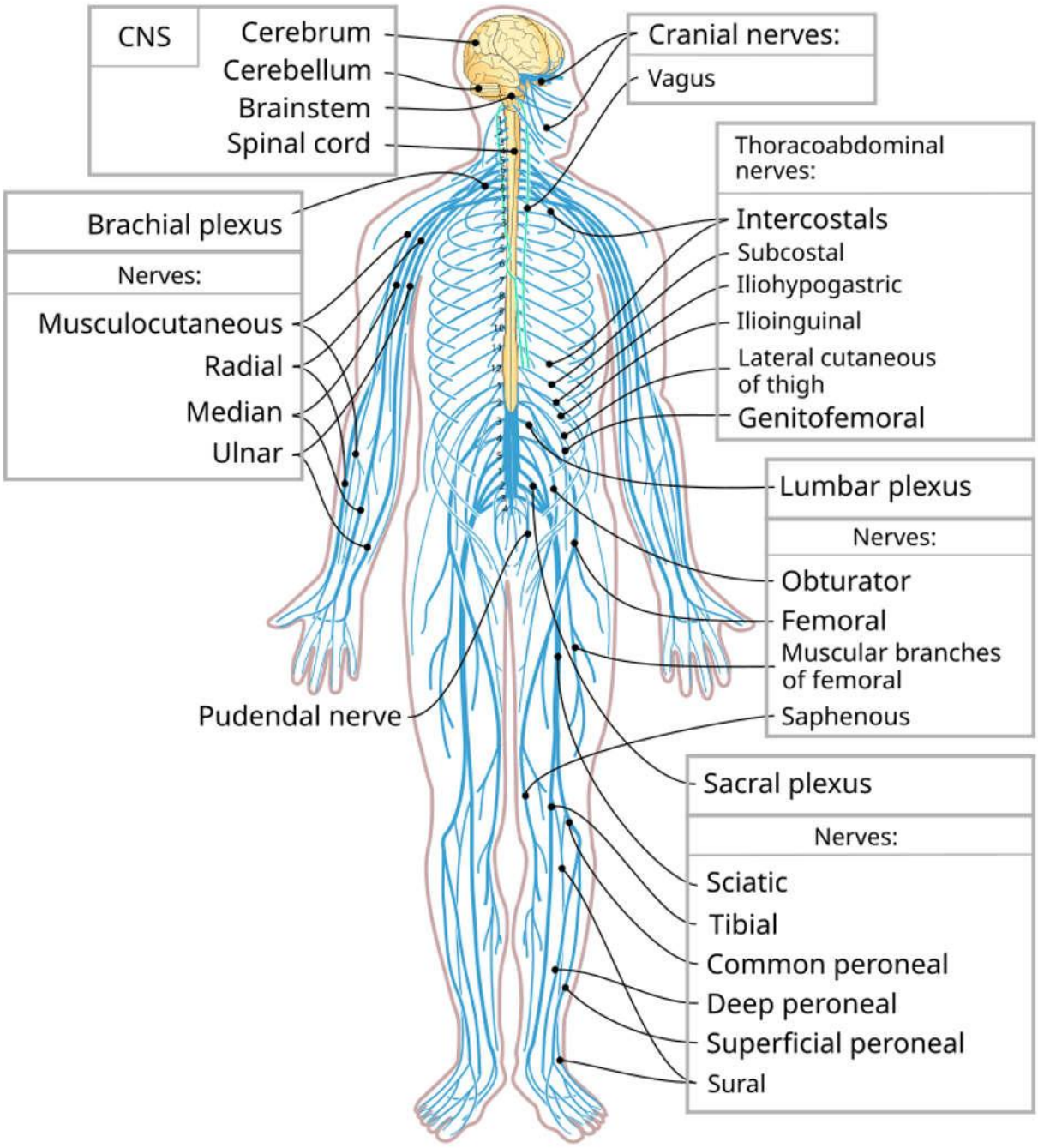
They discovered a striking bottleneck. The body’s peripheral nervous system works with incredible speed, collecting sensory input from the environment almost instantly. Yet the

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

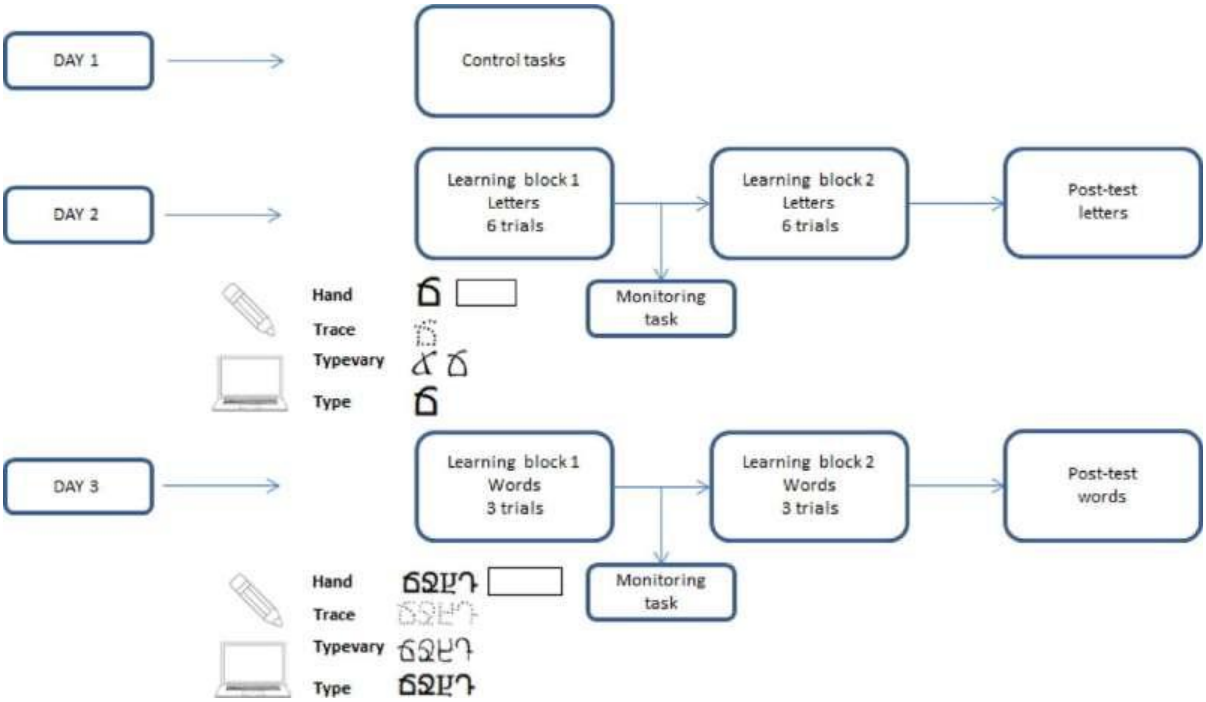
This slow speed of thought has significant implications for neuroscience and future technology. For instance, tech visionaries have proposed direct brain-computer interfaces to accelerate communication. However, the study’s findings suggest that such interfaces would still operate at the brain’s intrinsic 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.

APRIL 30, 2025

Children's reading and writing develop better when they are trained in handwriting, study finds

by University of the Basque Country



Credit: *Journal of Experimental Child Psychology* (2025). DOI: 10.1016/j.jecp.2025.106195

Nowadays, it is common for children's classrooms to have digital resources to be used as tools for certain learning processes. For example, there are computer programs geared toward children who are learning to read and write. Since the exercises that they propose are to be done on computer, the students press keys and buttons, and do away with pencil and paper.

To measure the impact of these typing-based methods, a UPV/EHU study has made a comparison to analyze the effects of manual and keyboard training on children's skills. The work appears in the *Journal of Experimental Child Psychology*.

"As children write less and less by hand, we wanted to explore the impact of this on alphabetic and orthographic skills. In other words, we wanted to see whether the ability to learn letters and to assimilate and remember word structure develops differently through manual training or the use of keyboards. We concluded that the children who used their hands obtained the best results," explained researcher Joana Acha.

To reach this conclusion, an experiment was conducted with 5 to 6-year-olds. This age was chosen because it is the most favorable moment in their development. This is in fact when children begin to acquire the ability to read and write. Fifty children with basic reading comprehension were taught nine letters from the Georgian and Armenian alphabets, as well as 16 pseudowords invented by researchers through combining the letters.

"The aim was to use letters and words that were completely new to the children to make sure they were learning from scratch. In fact, the studies carried out so far used the alphabets in the children's culture, so it is not so easy to find out the extent to which they did not know the symbols presented," said Acha.

Therefore, all the students were taught new letters and words, but not all in the same way. Half of them were asked to copy them by hand and the other half with keyboards. That way, the study was able to focus on the importance of the graphomotor function. In other words, the effect moving the hand will have on the reading and writing process. In fact, when we write on keyboards we do not trace the shape of the letter, and so the graphomotor function exerts less influence when it comes to assimilating letter and word structure. By contrast, writing by hand exerts a greater influence.

"Once we had taught each group of children the new letters and words and trained them using one method, we submitted them to three tests to assess the knowledge acquired. We measured their ability to identify, write and pronounce both the letters and the pseudowords, and the results clearly indicated that those who had practiced manually developed greater skill.

In particular, the difference was clear with the pseudowords; almost everyone who had learned on computer did not complete the exercises on letter sequences correctly. So our work confirms that the graphomotor function is essential in memorizing letters and word structures," explained Acha.

Variability also exerts an influence

However, the team did not look at the impact of the degree of hand movement alone. The groups who were working by hand and with keyboards were divided into two subgroups from the start. During the teaching of the letters and the words, among those who were working with pencils, some were asked to follow the guides marked with small dots (technique of low variability). The others, by contrast, practiced without any reference at all: copying freely on to the blank page (great variability).

The researchers did the same with those who were working on computer: some always used the same font for training (e.g. Tahoma), and others, more than one. That way, the researchers were able to analyze the influence of the shape variability factor in addition to the grapho-motor function.

What they saw was that all those who had been trained by hand were more competent than all those who had worked with keyboards, but even among those who had practiced with

pencil and paper, there were differences. Those who had been trained freely obtained the best results.

"So we concluded that while it helps children to have to trace in order to practice at first, once they're able to make more or less small, precise movements, it's advisable to move on to free writing. However, what is most clear is the need to prioritize manual practice in the learning processes. They learn best from hand movements and so technological devices should only be used in a complementary way," said Acha.

More information: Gorka Ibaibarriaga et al, The impact of handwriting and typing practice in children's letter and word learning: Implications for literacy development, *Journal of Experimental Child Psychology* (2025). DOI: 10.1016/j.jecp.2025.106195
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Psychedelics may induce right-brain dominance, researcher proposes

by Emily Caldwell, The Ohio State University

The secret to psychedelic drugs' links to greater empathy and insight may lie in their ability to coax the right hemisphere of the brain into a position of dominance over the left, according to a proposed new theory.

Researcher Adam Levin has combined his experience in therapeutic psychedelics research and psychiatric training with a review of imaging, numerous studies and previous models to support his proposal, published in the *Journal of Psychopharmacology*.

In this context, Levin emphasizes not what the two brain hemispheres do, but how they approach a topic or task—working in parallel, with left-brain dominance, during typical modes of consciousness.

When we're solving a problem, or—evolutionarily speaking—hunting for food, for example, the scope of attention differs: The left hemisphere focuses on manipulation of individual parts while the right hemisphere maintains a big-picture frame of reference.

"In the psychedelic state, there's a unique combination of the hemispheres coming together in a way that doesn't usually happen in normal states of consciousness," said Levin, a postdoctoral scholar and psychiatrist in the Center for Psychedelic Drug Research and

Education in The Ohio State University College of Social Work. "It's almost a new encounter between the left and the right hemispheres' way of thinking and perceiving the world."

He calls this model of psychedelic action HEALS: Hemispheric Annealing and Lateralization Under Psychedelics. In effect, he suggests, psychedelics reverse the hierarchical relationship between the two hemispheres of the brain, releasing the right hemisphere from inhibition by the left.

Levin was initially inspired in part by the writings of Iain McGilchrist, author of "The Master and His Emissary: The Divided Brain and the Making of the Western World." But his own clinical experience as a medical student and psychiatry resident gave Levin an up-close look at how disorders affecting one side of the brain or the other affected patients' worldview.

"In people who lose the right hemisphere to stroke, the attentional window gets so narrow and they don't even recognize a whole half of the world. Whereas people with an intact right hemisphere, who lose their left hemisphere, still have a broader general picture of things," he said. "A lot of these people's experiences seem, to me, to be similar to what I'm seeing in my psychedelic research."

Previous hypotheses about psychedelics' effects on the brain have suggested "unrestrained cognition" occurs through the weakening of control exerted by frontal lobes and the top of the brain.

While that is likely true, Levin said, patterns observed in people's reports of their psychedelic experiences suggest there's more going on: There are increases in psychological flexibility, creativity, and social and emotional intelligence; greater empathy, harmony and connection; a broader attentional window toward novelty and "aliveness"; and clarity and insight about one's basic existence, and in some cases, need for healing.

"Those general patterns are awfully similar to the pattern of the right hemisphere," he said. "And I think psychedelics provide access to this whole picture, this whole view, that could have been operating in the background—and that's this right hemisphere view. Restoration of this natural balance is an interesting way of explaining some of what's happening."

Neuroimaging studies of lateral changes to brain blood flow and metabolism—brain regions' use of glucose—that Levin analyzed showed signs of heavy activity in the frontal lobes in the right hemisphere as well as an overall rightward shift in metabolic activity under psychedelics, he said.

The growing evidence that mindfulness meditation practice is linked to building new networks in the brain and increasing brain thickness in the right hemisphere is relevant to the HEALS theory, as well.

"Psychedelics have been linked to improvements in mindfulness with just one or two uses. And sometimes these capacities are almost at levels consistent with practiced meditators,"

Levin said. "That makes it likely, to me, that many core right-sided networks that are enhanced with practicing meditation might be enhanced briefly, or maybe longer, through psychedelics.

"I think there's an opportunity after the use of psychedelics to increase and sustain mindfulness capacities in these areas of the right hemisphere."

The field of psychedelic research is focused on therapeutic applications at Ohio State and elsewhere, but Levin expects that expansion of the field will stimulate pursuit of other research questions—including testing theories about how these substances act on the brain.

He considers HEALS a complement to earlier theories about psychedelic action, and expects the growth in research to produce more hypotheses.

"I think to explain something as complex as the brain, especially in the human being, you need a variety of theories to more closely approximate what's actually happening," he said. "If we get too fixated on one explanation or the other, we're going to lose track of reality."

More information: Adam W Levin, Hemispheric annealing and lateralization under psychedelics (HEALS): A novel hypothesis of psychedelic action in the brain, *Journal of Psychopharmacology* (2024). DOI: 10.1177/02698811241303599
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