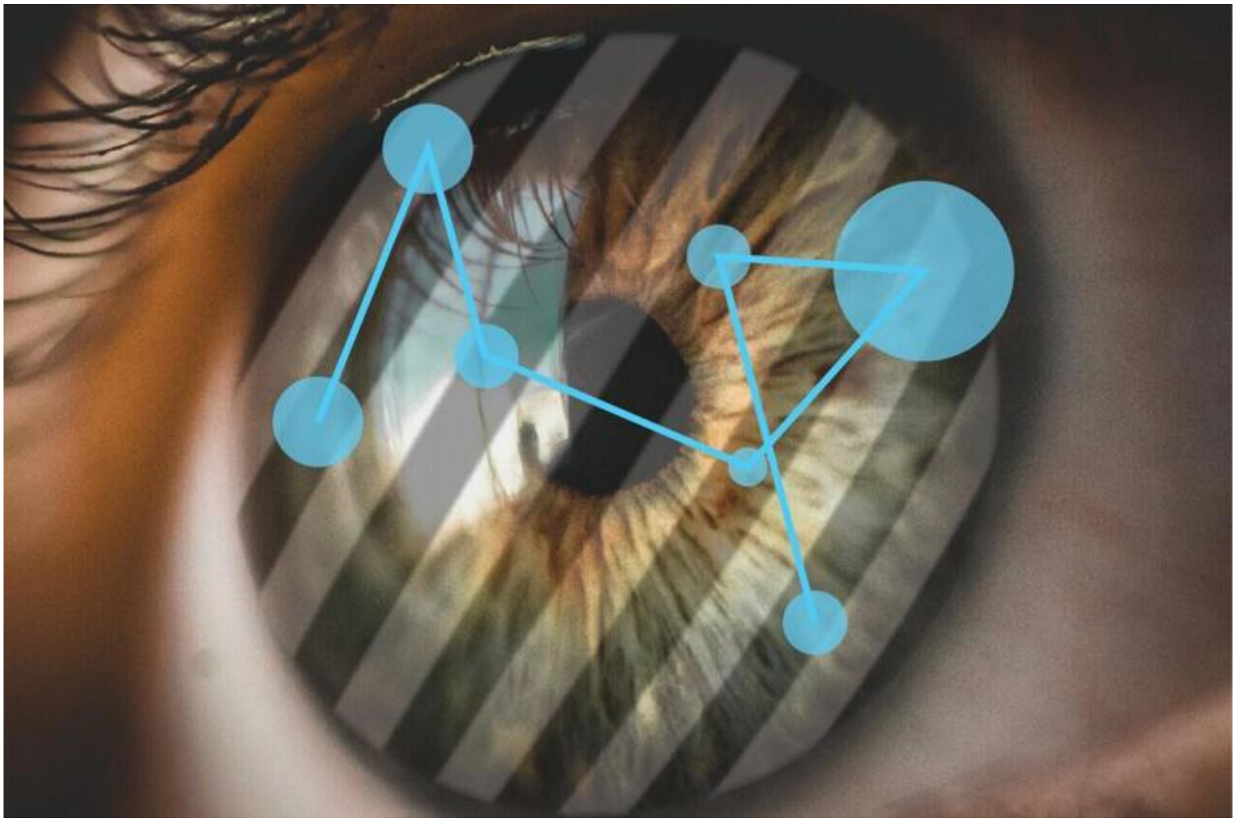
Neuroscientists reveal how brain coordinates attention and eye movements



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

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

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

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

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

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

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

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

In the other study, published in *Science Advances* and carried out with collaborators at Stanford University, the researchers devised an unusual experiment—this time, to decouple attention from eye movements—in monkeys. Their goal was to tease out what is happening in the brain while these processes play out.

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

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

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

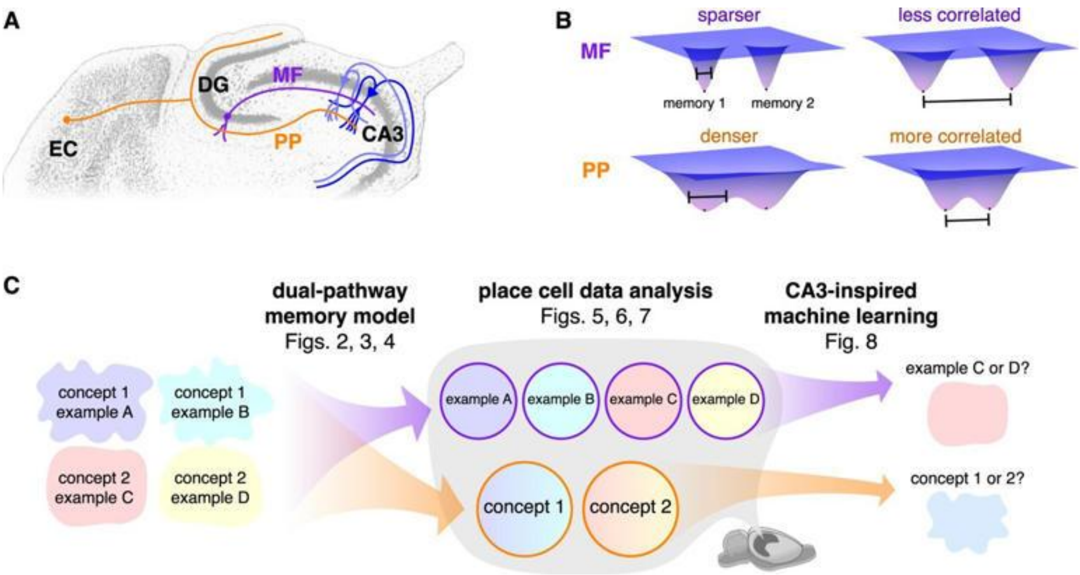
The researchers believe that uncovering such brain signatures can eventually point to what fails in attention disorders. Sridharan says, "Discovering such mechanisms is vital for developing therapies for disorders like ADHD."

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

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

Provided by Indian Institute of Science

Hippocampus uses dual pathways for memory storage



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

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

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

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

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

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

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

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

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

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

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

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

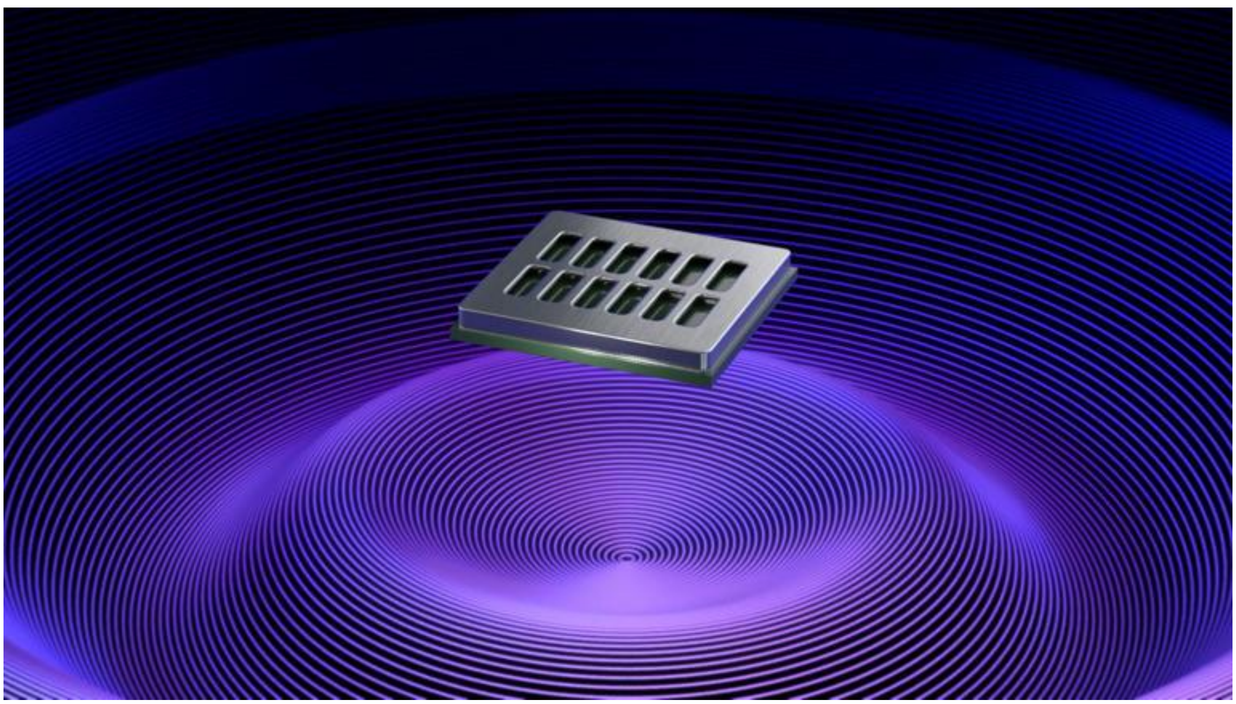
"This work shows how biological intelligence can inspire better algorithms for artificial intelligence," notes Kang.

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

Louis Kang et al, Hopfield-like network with complementary encodings of memories, *Physical Review E* (2023). DOI: 10.1103/PhysRevE.108.054410

Provided by RIKEN

Tiny Speaker Promises Big Sound From Smartwatches and Smart Glasses



Tiny Speaker Promises Big Sound From Smartwatches and Smart Glasses© xMEMS Labs

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The latest micro fidelity driver from xMEMS Labs is not meant to go inside typical audio products like earphones or headphones. Instead, the full-range Sycamore speaker aims to bring audio to a wide variety of wearable devices that broadcast sound near your ear rather than inside it.

The jump in quality should make such devices far better at delivering enjoyable audio experiences beginning in late 2025.

The Sycamore micro-electromechanical systems (MEMS) driver measures 8.41 by 9 by 1.13mm (HWD) and weighs 150 milligrams. It's one-seventh the size of a typical dynamic driver and one-third the thickness, xMEMS Labs says. This, in turn, reduces the area needed behind the driver to produce good sound.

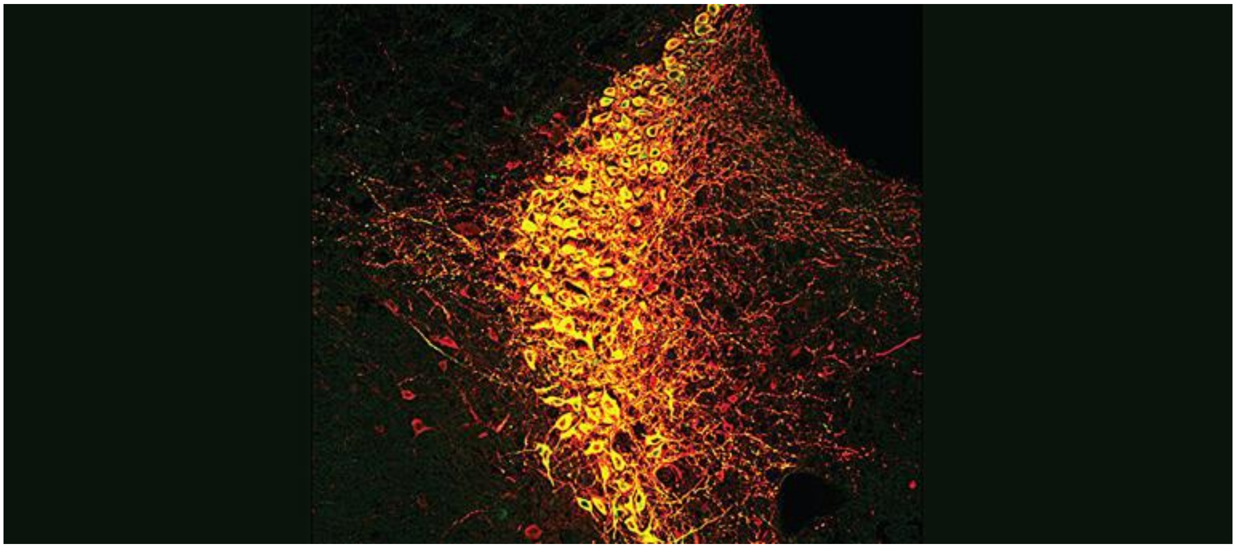
It's this incredibly small size that allows it to fit inside the confines of spaces like smartwatches, smart glasses, and other wearables. The "membrane" that moves is made from silicon rather than a more fluid material like paper or rubber, and it is much more rugged, earning an IP58 rating for protection from sweat or rain—a key feature for devices meant to be worn.

(Credit: xMEMS Labs)
Despite its small size, xMEMS' Sycamore doesn't skimp on performance; the driver covers a full range of audio, including sub-bass, mid-bass, and high frequencies, xMEMS Labs claims. It can do so at surprisingly high volumes, which allows it to push sound across the air between the device and the wearer's ear.

Target devices include open wireless earbuds, XR headsets, and more. "The applications for Sycamorel...are limited only by designers' imagination," xMEMS Labs says.

Sampling for the Sycamore begins in early 2025, with full production slated to start in October.

The brain's state of attention is shaped by a handful of neurons, study shows



Noradrenergic neurons in the locus coeruleus (LC) play a key role in the transition from a focused to an alert state. The image shows these neurons in a mouse brain, revealed by immunohistochemical staining. Credit: UNIGE / ETH Zurich

What enables the brain to go from intense concentration to a heightened state of alertness? A study carried out by neuroscientists at the University of Geneva (UNIGE), in collaboration with ETH Zurich, shows that a brain region called locus coeruleus (LC) and the neurotransmitter noradrenaline act as conductors, reorganizing brain functions according to the mental demands of the moment.

The study, published in *Nature Neuroscience*, demonstrates that the way the locus coeruleus is triggered enables us to switch from one state of concentration to another. This discovery could change the way elite sportsmen and women train to achieve their goals.

How do athletes achieve the extraordinary mental clarity and precision needed to succeed in their discipline? The answer lies in the brain's remarkable ability to focus, eliminating distractions to concentrate on a single task.

This phenomenon, often described as "being in the zone," is a critical skill not just for athletes, but for anyone facing a challenging task—whether it's taking an exam or mastering a musical instrument. At times, however, these people also need to be fully aware of their environment, especially when it comes to spotting potential dangers.

A handful of neurons

In this study, neuroscientists from UNIGE and ETH investigated what allows the brain to shift between intense focus and heightened awareness. The research team focused on the locus coeruleus (LC), a small region in the brainstem that produces noradrenaline, a neurotransmitter involved in regulating arousal.

"It's small and its location deep within the brain was a challenge from the outset, making it difficult to observe—and impossible to manipulate—in humans. For these reasons, we turned to mice where the LC consists of only about 3,000 neurons, but these neurons can still exert a significant influence over the 75 million neurons that make up the mouse brain," explains Valerio Zerbi, assistant professor in the Department of Psychiatry and the Department of Basic Neurosciences at the UNIGE Faculty of Medicine, and initiator of the study.

To overcome this challenge, his team collaborated with Johannes Bohacek's laboratory at ETH Zurich. Using advanced techniques such as optogenetics to artificially manipulate LC neurons and photometry to measure noradrenaline release, the researchers were able to explore LC function.

Functional Magnetic Resonance Imaging (fMRI) provided the first empirical evidence into how LC stimulation affects brain activity across different regions, shedding light on the LC's role in dynamically modulating attention and focus.

A question of rhythm

Neuroscientists discovered that triggering the LC three times a second in a continuous manner—so-called "tonic" activity—had different consequences than triggering the same frequency over a short period of time—so-called "burst" activity.

"When the LC is triggered in bursts, more noradrenaline is released, and the brain's sensory functions are prioritized. This sensory brain mode enables mice to be more alert to the environment around them," explains Zerbi.

Conversely, when the LC is triggered in a moderate tonic mode, less noradrenaline is released by the LC and brain regions such as the prefrontal cortex and hippocampus are activated. These two structures are known for processing information and are conducive to reflection and intense attention.

Controlling the locus coeruleus for performance

"While cutting-edge equipment and meticulous training are certainly part of the equation, the secret of top athletes may well lie in their mastery over their LC. By finely tuning its activity, they can switch between states of intense focus and broad awareness, performing at their peak when it matters most," concludes Zerbi.

Also, thanks to the findings of this study, brain imaging could help sportsmen and women to make better use of their LC, notably by using neurofeedback approaches, a technique that uses devices to monitor brain activity in real time to enable a person to regulate it based on visual feedback.

More information: Christina Grimm et al, Tonic and burst-like locus coeruleus stimulation distinctly shift network activity across the cortical hierarchy, *Nature Neuroscience* (2024). DOI: 10.1038/s41593-024-01755-8. www.nature.com/articles/s41593-024-01755-8

Provided by University of Geneva

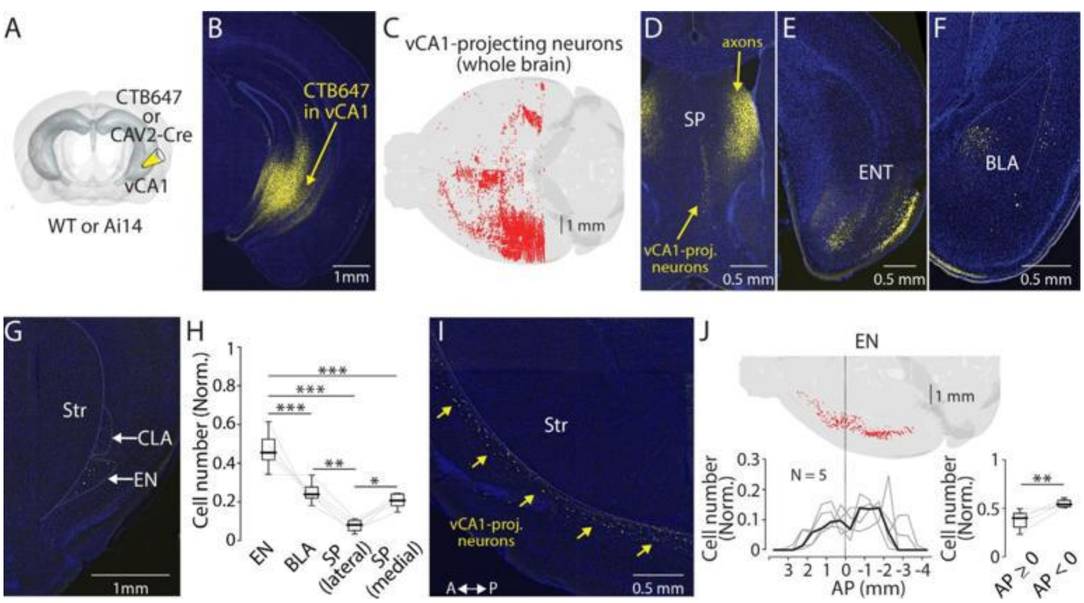
Researchers discovered the part of the brain that controls memory and information recall

The claustrum complex, a small yet powerful region in the brain, has intrigued scientists for years. Found across mammalian species, reptiles, and birds, this conserved brain structure is believed to play a pivotal role in higher-order cognitive functions.

With extensive connections across both cortical and subcortical areas, the claustrum coordinates neural activity on a global scale. This interconnectivity links the claustrum to various cognitive functions such as sensory perception and attention, which in turn affect processes like working, associative, and recognition memory.

Abnormalities within the claustrum are also linked to cognitive disorders, including Alzheimer's disease, schizophrenia, and attention-deficit/hyperactivity disorder (ADHD).

Researchers have long speculated on the microstructure and unique functions within this brain region, but the exact workings remained unclear. Now, a groundbreaking study from Aarhus University has shed new light on one of its subregions: the endopiriform nucleus (EN). This discovery offers a deeper look into how specific neurons within the EN contribute to recognition memory, offering insights that may eventually help in treating cognitive disorders.



Schematic diagram of a retrograde tracer injection performed. CAV-2-Cre or CTB647 was used in combination with Ai14 or wild-type mice, respectively. (CREDIT: eLife)© The Brighter Side of News

The claustrum complex is divided into two parts based on its cellular structure and genetic expression: the dorsal region, known simply as the "claustrum," and the ventral region, or the "endopiriform nucleus." The dorsal claustrum connects broadly with sensory, motor, and association areas in the cortex, producing different physiological effects depending on its target areas.

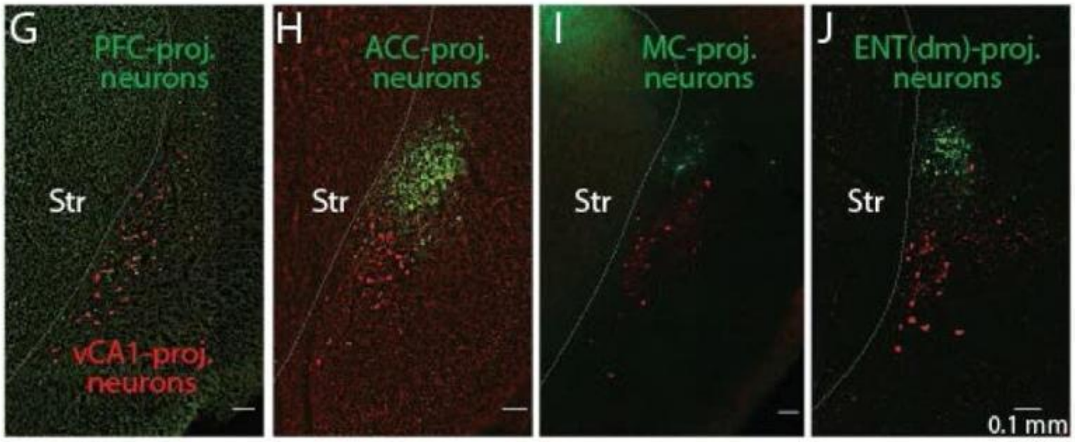
In contrast, the EN forms connections with the piriform cortex, which processes olfactory information, and the limbic system, which is critical for memory and emotional processing. This division suggests that each part of the claustrum has a distinct role in organizing and transmitting information.

One of the primary functions of the endopiriform nucleus is its connection to the ventral CA1 (vCA1) region of the hippocampus, a brain area known to regulate behaviors associated with exploration and recognition memory. Based on this connection, researchers hypothesized that the EN is a key node for establishing recognition memory. To explore this, they used advanced genetic tools and mouse models, focusing on a specific group of EN neurons that project directly to the vCA1, dubbed "EN vCA1-proj. neurons."

Through experimentation, they discovered that EN vCA1-proj. neurons connect with multiple parts of the limbic system, though not with the amygdala or prefrontal cortex. These neurons provide a potent inhibitory signal to vCA1 pyramidal neurons, effectively controlling their activity.

Interestingly, during recognition memory tests, EN vCA1-proj. neurons became active around new objects or other mice, guiding the subjects to spend more time exploring novel stimuli. When the researchers suppressed EN vCA1-proj. activity, the mice's ability to explore and distinguish new stimuli was diminished, indicating the EN’s role in recognition memory and its contribution to memory-guided exploration.

The significance of this finding is underscored by the practical implications it may hold. Daily, you encounter new people, situations, and objects, each requiring your brain to recognize and differentiate between familiar and unfamiliar stimuli.

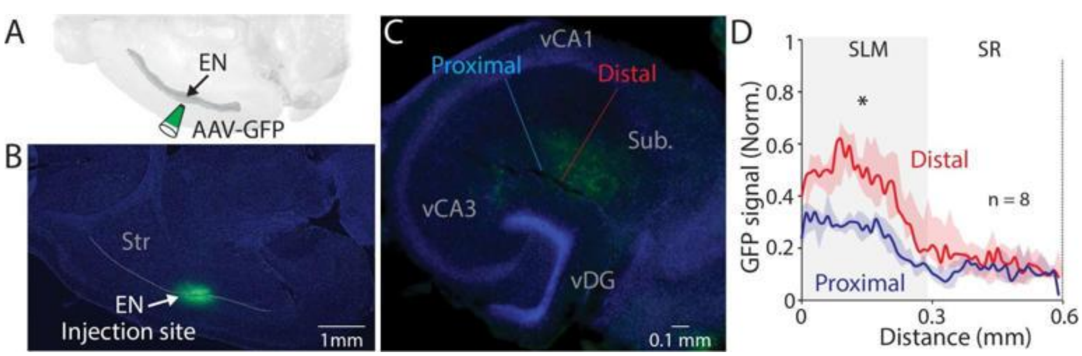


Example fluorescent images of retrogradely labeled neurons in CLA complex. vCA1-projecting neurons were colored in red and cortex-projecting neurons were colored in green. (CREDIT: eLife)© The Brighter Side of News

This cognitive function—critical for survival and social interactions—has now been linked to the claustrum complex and, more specifically, to the endopiriform nucleus. While previous research hinted at the claustrum's role in awareness and attention, this study demonstrates how the EN's connections to the hippocampus help guide attention based on memory.

Asami Tanimura, an associate professor and lead researcher on the study, explains, "Our study focuses on an area of the claustrum called the 'endopiriform,' which is a relatively unknown brain structure despite its unique network and cellular properties." She adds, "For the first time, we have dissected the circuit of the endopiriform to the hippocampus and demonstrated how this pathway is crucial for recognition memory."

Tanimura and her team's use of mouse models allowed them to observe the effects of turning on and off activity in this specific neuron group. Their findings reveal how the EN neurons' activity increases when mice interact with unfamiliar conspecifics or objects.

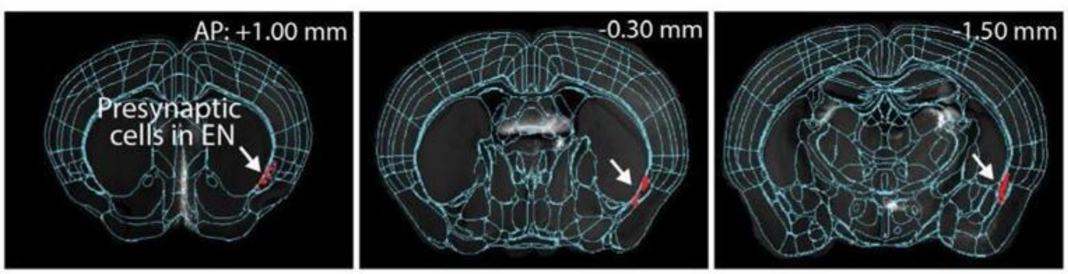


An example fluorescent image of horizontal brain section containing injection site in EN. (CREDIT: eLife)© The Brighter Side of News

Tanimura notes, "We observed that the cells in the endopiriform were active when the mice interacted with new conspecifics or objects, and when we inhibited this cell group, it reduced the mice's ability to distinguish novel mice or objects from familiar ones." This observation led the team to conclude that the endopiriform nucleus plays a vital role in sending memory-guided attention signals to the hippocampus.

The research goes beyond previous assumptions about the claustrum by identifying the exact circuit within the EN that contributes to recognition memory. This discovery opens new avenues for studying how the brain organizes complex cognitive functions and could eventually lead to targeted therapies.

Tanimura is optimistic about future applications: "To develop effective treatment methods, a very detailed understanding of the cells' circuits is required. With our study, we have at least opened a door that was previously closed in terms of understanding the specific role of the endopiriform-hippocampal circuit in higher cognitive function."

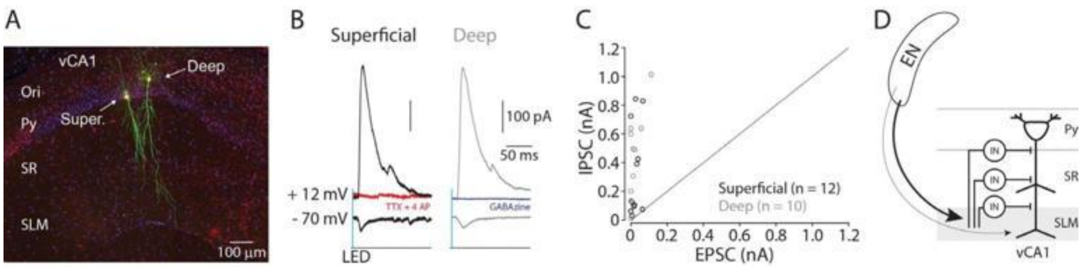


Example images showing presynaptic cells in EN (white arrow). (CREDIT: eLife)© The Brighter Side of News

The endopiriform nucleus's role in recognition memory could offer a foundation for treating cognitive disorders that impair a person's ability to distinguish familiar from unfamiliar stimuli. Disorders such as Alzheimer's disease and schizophrenia, which involve disruptions in memory and recognition processes, might one day benefit from treatments aimed at modulating the claustrum complex or its specific neural circuits.

The study also contributes to the broader understanding of how the brain manages attention and sensory information. By identifying this specific circuit, researchers are a step closer to decoding the intricate processes that underlie consciousness and memory.

Although much remains to be uncovered about the claustrum complex, Tanimura and her team's work has provided a crucial piece of the puzzle, demonstrating the claustrum's specialized role in recognition and memory-based attention.



A confocal image of recorded pyramidal neurons in vCA1. Recorded pyramidal neurons were filled with biocytin and post-labelled with Alexa488. Ori.: oriens, Super.: superficial layer pyramidal neuron. Deep: deep layer pyramidal neuron. (CREDIT: eLife)© The Brighter Side of News

While direct applications for humans may still be years away, these findings lay the groundwork for future research and potential therapies. As scientists continue to explore the claustrum's microstructure and its connections, they gain more tools to address disorders where memory and recognition are compromised.

This study is a promising step toward understanding and potentially enhancing the brain's remarkable ability to manage attention based on memory and recognition.

Groundbreaking neural technology can help people recall lost memories

The scientists in this study developed a new model aimed at assisting the hippocampus in recalling specific information.

The scientists in this study developed a new model aimed at assisting the hippocampus in recalling specific information. (CREDIT: Creative Commons)

A group of scientists from Wake Forest University School of Medicine and the University of Southern California (USC) has achieved a significant milestone in neuroscience by successfully utilizing a neural prosthetic device to recall specific memories.

Their findings, published online in Frontiers in Computational Neuroscience, mark a pioneering step forward in memory research.

The groundwork for this breakthrough stems from a previous study conducted by the Wake Forest and USC team in 2018, led by Dr. Robert Hampson, a professor specializing in regenerative medicine, translational neuroscience, and neurology at Wake Forest University School of Medicine.

This earlier study demonstrated the effective implementation of a prosthetic system harnessing an individual's own memory patterns to enhance the brain's capacity to encode and retrieve memories.

In their initial research, the team utilized an electronic prosthetic system based on a multi-input multi-output (MIMO) nonlinear mathematical model. By manipulating the firing patterns of multiple neurons in the hippocampus, a brain region crucial for memory formation, they achieved promising results.

Building upon their prior work, the scientists in this study developed a new model aimed at assisting the hippocampus in recalling specific information.

When the brain tries to store or retrieve particular memories, such as remembering to turn off the stove or locating misplaced car keys, distinct groups of cells collaborate in neural ensembles to activate and store the information. Leveraging recordings of this brain activity, the researchers devised a memory decoding model (MDM).

During the study, the research team delivered neurostimulation to study participants during visual recognition memory tasks. (CREDIT: Wake Forest University School of Medicine)

This model enabled them to decipher the neural activity associated with storing different pieces of specific information. Subsequently, the decoded neural activity was translated into a pattern or code, which was used to administer neurostimulation to the hippocampus during memory retrieval processes.

Dr. Brent Roeder, a research fellow in the department of translational neuroscience at Wake Forest University School of Medicine and the study's corresponding author, emphasized the significance of their approach: "Here, we not only highlight an innovative technique for neurostimulation to enhance memory, but we also demonstrate that stimulating memory isn’t just limited to a general approach but can also be applied to specific information that is critical to a person."

Delayed match to sample (DMS) task performed on a touch screen by patients seated in either the hospital bed or a chair. (CREDIT: Frontiers in Computational Neuroscience)

To test the efficacy of their method, the team recruited 14 adults with epilepsy undergoing a diagnostic brain-mapping procedure involving surgically implanted electrodes placed in various brain regions to identify seizure origins. These procedures took place at Atrium Health Wake Forest Baptist Medical Center, Keck Hospital of USC in Los Angeles, and Rancho Los Amigo National Rehabilitation Center in Downey, California.

During visual recognition memory tasks, the researchers administered MDM electrical stimulation to assess its impact on memory retention. The results revealed significant improvements in memory recall among participants who received the stimulation, with approximately 22% showing noticeable enhancements in performance.

Sample patterns from an individual patient for each of the categories. Unique patterns that were 4 s in length were derived for each subject for every patient using the MDM applied to each patient's own neural recordings. (CREDIT: Frontiers in Computational Neuroscience)

Moreover, when focusing on participants with impaired memory function who underwent bilateral brain stimulation, nearly 40% exhibited substantial improvements in memory performance. Dr. Roeder underscored the potential applications of their technology in aiding individuals with memory-related impairments: "Our goal is to create an intervention that can restore memory function that's lost because of Alzheimer's disease, stroke or head injury."

Despite these promising findings, Dr. Roeder stressed the need for further research to refine the technology and unlock its full potential in enhancing memory function. He expressed hope that advancements in MDM-based stimulation could empower individuals to live more independently by aiding in critical tasks such as medication management and home security.

Diagram of an individual-trial DR screen following DMS stimulation session. Images consist of the sample/match image, one Nonmatch image from the same trial, and one novel image not used in any prior testing. The "familiarity" choices displayed with each image are converted to a numeric ranking (0 = Do not recognize, 5 = Definitely saw) for scoring and analysis. (CREDIT: Frontiers in Computational Neuroscience)

This groundbreaking research builds upon over two decades of preclinical studies on memory codes led by Dr. Sam Deadwyler, emeritus professor of physiology and pharmacology at Wake Forest University School of Medicine, alongside Dr. Hampson and the USC team led by biomedical engineers Dr. Theodore Berger and Dr. Dong Song. The preclinical investigations utilized similar stimulation techniques to restore and bolster memory in animal models using the MIMO system developed at USC.

Funded by the U.S. Defense Advanced Research Projects Agency (DARPA), this research represents a significant stride forward in understanding and potentially enhancing human memory function. As scientists continue to unravel the complexities of the brain, innovations like these hold promise for addressing memory-related disorders and improving overall cognitive health.

Surprising connection between fatty acids and how the brain creates memories

Researchers have uncovered a significant breakthrough in understanding how the brain consolidates memories.

To investigate the significance of free fatty acids in memory formation, the researchers employed mouse models with the PLA1 gene removed, monitoring their neurological and cognitive functions over time.

"We saw that even before their memories became impaired, their saturated free fatty acid levels were significantly lower than control mice," Professor Meunier remarked.

"This indicates that this PLA1 enzyme, and the fatty acids it releases, play a key role in memory acquisition."

The findings from this study not only advance our understanding of memory formation but also offer promising prospects for therapeutic interventions in neurodegenerative diseases like Alzheimer's. "Our findings indicate that manipulating this memory acquisition pathway has exciting potential as a treatment for neurodegenerative diseases," Professor Meunier stated.

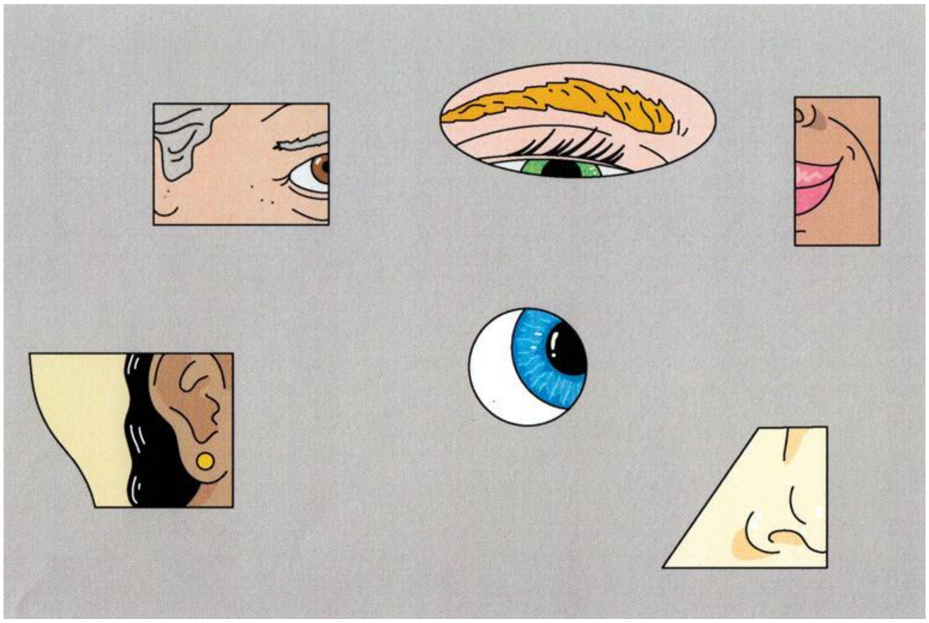
The research team acknowledges the valuable contributions of PhD candidates Saber Abd Elkader from the Australian Institute for Bioengineering and Nanotechnology, and Benjamin Matthews from the Queensland Brain Institute.

Behavioural responses to instrumental conditioning in DDHD2+/+ vs DDHD2−/− mice. Instrumental conditioning was performed on cohorts of DDHD2+/+ (WT) or DDHD2−/− (KO) mice vs controls, respectively. (CREDIT: The EMBO Journal)

This collaborative effort involved researchers from the University of New South Wales, University of Strasbourg, University of Bordeaux, The Scripp Research Institute, and the Baylor College of Medicine.

The research paper detailing these findings has been published in the prestigious EMBO Journal, marking a significant milestone in neuroscience research. With this groundbreaking discovery, scientists are now equipped with new insights into the intricate workings of memory formation, paving the way for innovative approaches to combat neurodegenerative disorders.

Are you a super-recognizer? The science of superior facial processing.



Are you a super-recognizer? The science of superior facial processing.© George Wylesol for The Washington Post

Do you remember the face of any stranger who passed by you today?

You probably can't, but super-recognizers can. These rare individuals can identify unfamiliar faces after a brief glimpse. And by studying them, researchers hope to understand how we recognize that a face belongs to someone we know — an important ability for a social species such as ours.

"The face is the most important visual stimulus for humans in their environment, probably throughout evolution," said David White, associate professor of psychology and lead investigator of the Face Research Lab at the University of New South Wales, Sydney. "We're a social species, and the information contained in the face is vital to behave rationally in a social environment."

We don't, for example, usually need to identify specific chairs, because knowing "it's just a chair" is enough, said Meike Ramon, an assistant professor and head of the Applied Face Cognition Lab at the University of Lausanne. "But for faces, it matters who each unique individual face belongs to."

Face processing on a spectrum

Our ability to recognize faces is part of a spectrum.

At one end are the 2 to 3 percent of people with face blindness — or developmental prosopagnosia — who have trouble recognizing faces that should be familiar to them, including those of loved ones or even their own.

At the other end are super-recognizers, first reported on in 2009, who excel at identifying or matching faces, even those that are unfamiliar to them — whether they are flipped upside-down, low resolution or presented at a different angle.

They have a “unique ability to derive a three-dimensional representation of a face, even when they see only one 2D image of the person,” Ramon said. Super-recognizers are rare, though how rare is hard to estimate because there is no single agreed-upon method for categorizing them.

Most people’s ability to process faces lies somewhere in between, where recognizing familiar faces is easy but deciphering unfamiliar ones is challenging.

What makes super-recognizers super

Super-recognizers are drawn to faces.

Even when they are presented with random pictures of everyday life, super-recognizers spend more time looking at faces, Ramon and her colleagues reported in one 2022 study.

Their eyes are also drawn immediately to the face, regardless of where that face is in the photo — and most closely near the optimal place for identification, below the eyes.

“It seems like faces are extremely salient for super-recognizers for reasons that we still don't know,” Ramon said.

Their brains also respond differently to visual images less than a second after seeing them.

In a 2024 study, Ramon and her colleagues recorded brain activity from 16 super-recognizers and 17 control participants using EEG while they viewed a variety of pictures, such as of plants, animals, scenes and faces. Even just 65 milliseconds after an image pops up — faster than the blink of an eye — their brains already start responding differently from neurotypical brains.

Interestingly, super-recognizers exhibited this difference in neural activity regardless of what they were looking at, which suggests that their brains process visual information differently in general.

Other research suggests that super-recognizers have broader activation of the brain's face-processing networks, even when looking at unfamiliar faces.

The super-recognizer ability to process faces may simply reflect how good they are at processing all visual information. And conversely, people with face blindness not only struggle with faces but may also have difficulties processing other types of visual information.

Curiously, however, super-recognizer abilities may extend beyond the visual domain. A 2021 study of 529 participants reported that super-recognizers were also much better at identifying unfamiliar and familiar *voices*, despite having merely average pitch discrimination, which may point to a "common basis for person identity processing abilities" across different senses, White said.

Still, super-recognizers have weaknesses. Just like typical recognizers, super-recognizers also find it more difficult to distinguish between the faces of people of ethnicities different from their own.

Getting better at recognizing faces

Identifying unfamiliar faces is tricky, even for experienced professionals such as forensics examiners and customs agents. Unfortunately, it is not possible to train people to become super-recognizers, which appears to be a natural ability.

When White and his colleagues pit super-recognizers against trained forensic examiners, the differences in their process for face identification were clear, though they achieved equivalent accuracy.

Super-recognizers were more intuitive and made their judgments quicker with great accuracy after just 2 seconds. They looked at faces more, but there was no clear pattern in where they were looking, the 2023 study reported.

Forensic examiners, by contrast, were much more methodical and systematic. They took longer to make their decisions, requiring up to 30 seconds, but picked up on facial clues that most people would not pay attention to.

"What super-recognizers are doing is more of a black box," White said. "It's more of an automatic processing."

The growing recognition of super-recognizers has increased interest in using their powers to aid policing and security work, though there appears to be no formal, systematic approach for identifying and deploying them. Ramon has worked with Berlin Police and White has worked with the New South Wales Police Force to identify super-recognizers.

But super-recognizers aren't perfect, White said.

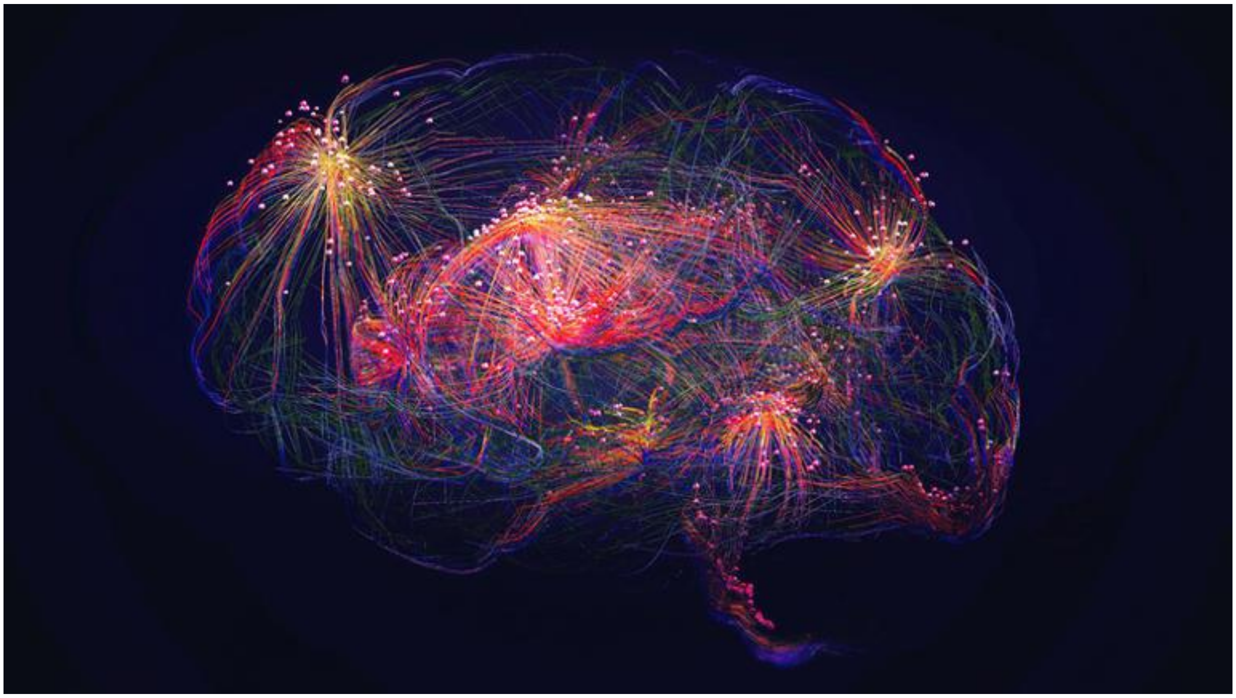
In White's research, when super recognizers and professionals made errors, super recognizers maintained a high confidence, while professionals were less confident.

So far, lessons on how to improve our facial processing come from trained experts.

In a 2021 study, White and his colleagues taught novice participants some of the tricks used by professional examiners, such as focusing on the ears, scars, freckles and blemishes. After just a six-minute training, the novices got somewhat better — an improvement of 6 percent in accuracy.

But more research on super-recognizers could help solve the mystery of how an unfamiliar face becomes a recognizable and familiar face. The fact that super-recognizers are able to do so well with unfamiliar faces may give us clues in how the brain makes that change, White said.

The Incredible Map That Shows Every Neuron In The Brain



Full, colorful concept of neuron activity in a human brain© Nopparit/Getty Images

Neurons are cells in the nervous system that send and receive messages throughout your body, allowing your brain to control everything you do. They're even involved in how your brain processes eating. Since there are about 86 billion neurons in the brain, the synapses that connect them look like an elaborate pile of spaghetti in raw images. Thanks to FlyWire and a consortium of researchers across more than 127 institutions, this chaotic network of circuitry is depicted in the first-ever full connectome of an entire adult female fruit fly brain.

Publishing the collection of flagship and companion papers in scientific journal Nature, the Princeton University-led FlyWire Consortium — which consisted of gamers and professional tracers among neuroscientists — used 21 million high-resolution images from the fly brain and a multistep process with AI and computer automation to untangle the web of undifferentiated neurons. The labeled, three-dimensional map includes around 100,000 cell annotations, almost

140,000 neurons, and more than 50 million synapses — all of which they started in 2019.

The flagship paper's lead author, Dr. Sven Dorkenwald of Princeton University, told Princeton's Office of Communications, "What we have done is build an atlas of the brain, and added annotations for all the businesses, the buildings, the street names. With this, researchers are now equipped to thoughtfully navigate the brain, as we try to understand it." This feat is so amazing because of its complexity to previous brain models, such as the 302 neurons of an adult roundworm and the 3,000 neurons of a larval fruit fly.

Read more: Pros And Cons Of Recombinant DNA Technology

Why The Fruit Fly Brain Model Can Aid Human Neurological Research

Close-up, colorful concept of a neuron network in the brain© Christoph Burgstedt/science Photo Library/Getty Images

To the general public, it might not seem very productive toward human neurological research for scientists to work so hard on an insect wiring diagram, but fruit fly brains actually have quite a bit in common with ours. For starters, we share 60% of DNA, including genes for jet lag, learning, and chromosomal abnormalities. The insects serenade love interests, stay awake with coffee, get drunk, age the same, and problem-solve like we do, too. On top of that, 75% of human genetic diseases have similarities with fruit flies.

Currently, many human neurological diseases are incurable — such as Alzheimer's, Parkinson's, and dementia — so doctors are only able to treat the symptoms. Now, researchers will be able to use this brain atlas to understand how all brains function, how neurons connect with one another, and which neurons and behaviors correlate. It will allow them to understand the difference between a healthy and diseased brain, paving the way for tailored treatments. A 2019 study was published regarding how fruit flies could cure chronic pain, for instance, and this new brain model could further that research.

The FlyWire Consortium created a free Codex so that professionals around the world can navigate the comprehensive map without needing advanced tools or downloading excessive amounts of data. More than 10,000 users had registered for it as of early October 2024, and new experiments are already underway. Plus, the team created a collection of resources for high school and college students to learn from, which may expand its application and potential in neurological research.

Read the original article on Sciencing.

Thyroid hormone fuels the drive to explore by rewiring brain circuits, new study suggests

Credit: Pixabay/CC0 Public Domain

Thyroid hormone plays a key role in regulating a range of physiologic functions, including metabolism, temperature, heart rate, and growth. It accomplishes this impressive array of activities by interacting with almost every organ system in the body. Yet despite a long history of research on how thyroid hormone influences different organs, its effects on arguably the most crucial organ—the brain—have remained shrouded in mystery.

Now, scientists at Harvard Medical School have gained new insights into thyroid hormone's effects on the brain. The work, conducted in mice and published Aug. 22 in *Cell*, shows that thyroid hormone changes the wiring of brain circuits in a manner that drives animals to engage in exploratory behavior.

By simultaneously changing brain wiring and altering metabolic rate, the researchers concluded that thyroid hormone coordinates the brain and body to produce exploratory behavior when it is most needed—for example, during seasons when animals need to find mates or stockpile resources.

"It's well known that thyroid hormone modulates metabolism, and now we've shown that it also modulates exploratory behaviors through direct action on the brain," said lead author Daniel Hochbaum, research fellow in neurobiology in the Blavatnik Institute at HMS.

The findings also help elucidate how low levels of the hormone could lead to depressive states marked by a low desire to explore, while too much could precipitate manic states characterized by an extreme desire for exploration. Thus, the researchers see their work as an important step toward understanding how aberrant levels of thyroid hormone could contribute to certain psychiatric conditions.

Propelled by a personal purpose

Hochbaum's interest in thyroid hormone is a personal one: His wife was diagnosed with hyperthyroidism after experiencing profound and sudden behavioral and metabolic changes. Her symptoms resolved with treatment, but Hochbaum wanted to know more about the hormone's effects on the brain.

"I was really surprised to see that thyroid hormone had large psychiatric effects," Hochbaum said.

He learned that too little thyroid hormone slows down metabolism and can result in symptoms of depression, while too much speeds up metabolism and can lead to symptoms of mania. Yet he couldn't find a satisfactory scientific explanation for how this happens.

During a serendipitous conversation with Bernardo Sabatini, the Alice and Rodman W. Moorhead III Professor of Neurobiology at HMS, Hochbaum found that Sabatini shared his interest in the topic.

"Why thyroid hormone changes behavior has been something that's puzzled me ever since medical school," said Sabatini, who is also director of the Kempner Institute for the Study of Natural and Artificial Intelligence at Harvard University and senior author on the new study. "It was not clear why this hormone should even enter the brain at all."

And with that, a project to explore thyroid hormone's function in the brain was born.

Linking brain, body, and behavior

Thyroid hormone circulates in the bloodstream, traveling to almost every cell and tissue in the body. Its levels are controlled by a complex set of interactions between three players: the thyroid gland, the pituitary gland at the base of the brain, and the hypothalamus, a brain structure located just above the pituitary gland.

However, the receptor for thyroid hormone is expressed by cells throughout the entire brain, including in areas of the cortex responsible for high-level cognition like planning and decision-making.

"What is quite remarkable is that in the adult brain, the thyroid hormone receptor is not only in the hypothalamus, but it's basically everywhere," Hochbaum said.

To investigate why, Hochbaum, Sabatini, and their team performed genetic sequencing on individual cortical cells in mice. They found that the hormone acts on neuronal circuits in the cortex by turning on various genes, essentially changing the wiring of brain cells.

Moreover, when researchers induced higher levels of thyroid hormone in the cortex, mice became more willing to explore the environment and take risks.

Conversely, when researchers blocked the hormone's action in only the cortex, the animals no longer changed how much they explored based on thyroid hormone levels.

"This told us that thyroid hormone is doing important things directly in the cortex," Hochbaum said.

Yet the findings raised a new question: Why would it be beneficial for a hormone that controls metabolism to also alter brain circuits that affect behavior?

To address this question, the researchers turned to previously published field studies that observed behavior in the wild and measured thyroid hormone of lemurs, squirrel monkeys, and other mammals. The research revealed that hormone levels, and in turn metabolic rates, tended to be higher in warmer seasons when food and resources were more abundant—and animals explored more during those seasons.

The studies, combined with the new findings, Hochbaum said, provide an essential missing link between thyroid hormone's effects on the brain and body.

"We think that thyroid hormone acts directly on brain circuits to coordinate exploratory behaviors with metabolic rate," he added. "It's syncing up your brain and body for the current environment."

Or, as Sabatini put it, "It seems like thyroid hormone prompts the body to tell the brain to go explore and capture resources."

Looking ahead

The way in which thyroid hormone regulates physiology is highly conserved between humans and other mammals, the researchers said, so they suspect that a similar brain-body connection exists in humans.

In fact, a 2024 study led by the same researchers linked higher thyroid hormone levels in U.S. adults to greater employment levels and more hours worked.

The researchers are now exploring this connection in people in Indonesia who experienced the 2004 tsunami. They are interested in whether psychological trauma from the natural disaster has led to long-term changes in thyroid hormone levels.

The team also wants to investigate the basic biology of the exploratory brain circuits that are activated by increased thyroid hormone. The researchers hope that their work could highlight brain circuits relevant to psychiatric conditions such as depression and bipolar disorder.

"The thought is that these conditions are also shaping exploratory activity, so perhaps manipulating thyroid hormone to change brain circuits will reveal relevant points of entry for treatment," Hochbaum said.

More information: Daniel Hochbaum et al, Thyroid hormone remodels cortex to coordinate body-wide metabolism and exploration, *Cell* (2024). DOI: 10.1016/j.cell.2024.07.041. www.cell.com/cell/fulltext/S0092-8674(24)00835-3

Provided by Harvard Medical School

Samsung is eyeing smart glasses that could shake up the market

Samsung is ready to take a stab at another wearable segment, less than a year after introducing its first smart ring. A Shenzhen-based research company, Wellsen XR, shared in an investor note about Samsung's plans to launch smart glasses that could arrive late next year, or early in 2026.

"Samsung Electronics' plan to release AI smart glasses was confirmed earlier this month, and its first production volume is 500,000 units in the third quarter of 2025," says the note, which was reported by Maeil Business Newspaper.

Interestingly, Samsung is not chasing something too ambitious, or innovative in terms of the tech stack. Instead, the company is taking the safe route and eyeing the same formula as the runaway success that was the Meta Ray-Ban Stories smart glasses, down to the core internal hardware.

The Samsung smart glasses will reportedly come armed with Qualcomm's AR1 Gen 1 wearable silicon and an NXP semiconductor as a secondary processing unit. Multimedia capture duties will be handled by a 12-megapixel camera with a Sony CMOS sensor at its heart.

Ray-Ban Meta (top) and Solos AirGo 3 smart glasses. Andy Boxall / Digital Trends

The smart glasses are said to draw power from a 155 mAh battery and tip the scales at 50 grams. As far as capabilities go, the front camera sensor will come in handy for code scanning, gesture recognition, and more, aside from the usual photo and video capture duties.

Despite the fundamental similarities with the Meta Ray-Ban smart glasses, the software stack would be different. Instead of the Meta AI bundle that is now available on the Stories smart glasses with multi-modal capabilities, Samsung will look at Google.

Specifically, the Korean electronics giant will put Google’s Gemini AI at the heart of its smart glasses. That partnership isn’t surprising, since Samsung’s Galaxy smartphones were also among the first to introduce native Gemini-powered features as part of its Galaxy AI bundle.

This would be quite a substantial edge, as Gemini already has been integrated deeply within Google's products, especially the Workspace suite that is used by hundreds of millions of users. At the moment, it can pull of a lot of meaningful tricks in products like Gmail, Docs, and more, while also letting users access custom AI agents.

Moreover, the Android collaboration would go a long way in seamlessly connecting the smart glasses with phones and other ecosystem products. However, Samsung won't be the lone player in the smart glasses game. Chinese archi rival, Xiaomi, is reportedly developing its own version that would try to emulate the success of Meta's offering.

These new smart glasses are set to bring spatial displays to the mainstream

I'm learning more about augmented reality (AR) smart glasses everyday, and I think they're probably the most underrated tech on the market right now. From Meta's ambition with futuristic frames to the immensely premium VITURE Pro specs for gaming, can it get any better?

Apparently so, as XREAL has just unveiled two new products including the world's first Cinematic AR glasses with the XREAL One and XREAL One Pro Series. These wearable displays are the first of their kind, and set to deliver next-generation three degrees-of-freedom (3DoF) spatial computing, while representing "the most advanced consumer AR glasses on the market" according to XREAL's co-founder and CEO, Chi Xu.

Our sister site, Tom's Guide, has already had the opportunity to get hands-on and try out these new XREAL One smart glasses with devices including an iPhone 16, a Steam Deck, and a MacBook. The verdict? They're pretty impressive.

These AR glasses are available for pre-order right now from XREAL's website starting at $499 / £449 for the standard specs, and $599 / £549 for the Pro option, which has a wider 57-degree field of view and brighter virtual screen.

((Image credit: XREAL))

XREAL has also developed its first silicon co-processing chip, the X1, which is built directly into the new specs and boasts independent spatial computing. Essentially, these AR glasses have the power to create a spatial display from nearly any compute device (though it must have the option for video-out over USB-C), introducing a cinematic virtual screen that is, for the first time, spatially controlled by the glasses themselves.

Explained in more simplified human words, what makes this launch so special is not only the unique X1 chip, but the fact that wearers can experience a stable virtual screen to display unlimited apps, games, websites, and productivity tools by anchoring this screen anywhere they choose in three-dimensional space, with the simple press of a button on the glasses.

This eliminates the need for the expensive Xreal Beam Pro device which is used for creating spatial displays and was required for previous XREAL specs like the Air models.


((Image credit: XREAL))

Other notable new features with the XREAL One and One Pro smart glasses include adjustable interpupillary distance (IPD) ranges, which is apparently a pretty big deal, plus multiple TÜV Rheinland eye health certifications meaning they're safe to replace physical monitors.

The glasses also have high-quality Sound by Bose fitted, plus there's an optional XREAL Eye detachable AI camera available for recording 12MP high-definition photos and video capture from the wearers' point of view. The front frame of the specs is interchangeable for a customised look, and the 4-microphone layout enables audio recording for meeting summaries, transcriptions and translations.

As both a photographer and gamer, these specs sound like an absolute dream. If you're hoping to preorder, keep in mind that the XREAL One Pro model won't be released until early 2025, but the regular XREAL One is expected to ship mid-December, which is perfect timing for Christmas.

Apple ramps up smart glasses project as it looks past Vision Pro

Apple ramps up smart glasses project as it looks past Vision Pro© Mac World

With Vision Pro failing to set the market alight-and being officially labeled as "not a mass-market product"–the big question is how Apple plans to build a commercially viable product in the VR/AR space, if that's even possible. Ultimately, the most appealing option for a mainstream audience would probably be a slimline pair of glasses with smart tech built in, but the state of technology and Apple's own developments mean this isn't likely to appear for some years yet.

There are signs of progress, however. In the latest edition of his Power On newsletter, knowledgeable Bloomberg reporter Mark Gurman claims that Apple recently commenced focus-group research to explore its options in the smart glasses market, in a sign of real intent. (This follows what was described as a technology investigation earlier this year.) Such groups previously preceded the launch of the AirPods and HomePod, and Vision Pro itself.

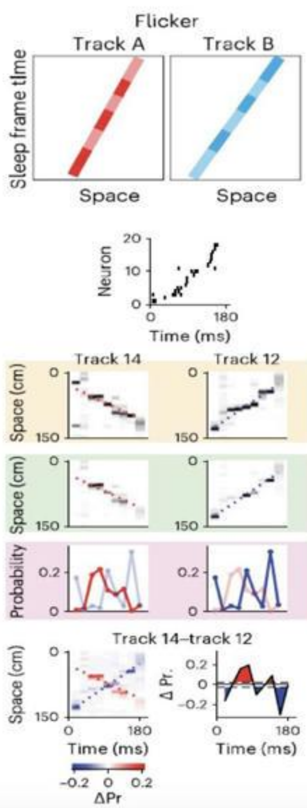
Rather than seek opinion from the public, Apple restricts focus group discussions to its own employees. This might seem less illuminating, but enables the company to keep a lid on future developments and prevent them from reaching the media… in theory. It isn’t clear how Gurman obtained his information on the proceedings in this case.

The groups have been discussing their feelings about currently available smart glasses, which include products from Snap and Meta. Apple is behind in this market, as it is so often–one of Cook’s mantras is “Not first, but best”–but those companies haven’t cracked the formula yet. Indeed, as Gurman observes, their products are far more limited in terms of AR functionality than what Apple is planning.

So the question becomes this: should Apple pursue its own more ambitious plan, and attempt to reproduce Vision Pro’s capabilities in a far smaller chassis? Or should it simply create “a version of its AirPods in glasses form,” as Gurman puts it? That’s the dilemma which the focus groups are intended to solve.

Whatever conclusion is reached, we won’t officially know about it for some time. Gurman says five years is the minimum before Apple is able to create a “true AR” set of smart glasses that meets its expectations. But Apple isn’t alone in this, with Meta and Snap experiencing similar issues with their own prototypes. Wherever the market is going, it isn’t going there yet.

Sequence of the day: Exploring how the mammalian brain represents multiple sequential experiences during sleep



Multiplexed parallel co-representation of two contexts within the same sleep frame. Top: Diagram of dynamics of 2-track parallel co-representation in a sleep frame. Color intensity marks decoded probability of track locations. 2nd row displays the spiking activity in the frame. 3rd row shows the decoded probabilities normalized within each track. The decoded probabilities normalized across the track pair (4th row) were used to extract the probabilities on the fitted line (5th row), which were compared to obtain the difference curve (6th row).

Credit: Liu, Sibille & Dragoi

Sleep is among the most fascinating phenomena observed in both humans and animals, known to be characterized by different cycles and types of brain activity. Past neuroscience studies have found that during sleep, groups of neurons in the hippocampus replay past experiences and forecast potential future experiences.

Researchers at Yale School of Medicine recently carried out a study investigating how these neuronal ensembles in the hippocampus represent several sequential experiences, or in other words, experiences or events that occur in a specific order.

Their paper, published in *Nature Neuroscience*, pin-points some of the processes that allow the brain to process numerous experiences during sleep, creating new mental representations that are often based on prior knowledge.

The key objective of the work by this team at Yale was to understand how the mammalian brain organizes several experiences without interference (i.e., encoding new memories without disrupting the older ones). The researchers also set out to explore what the capacity of the brain is for forming memories of multiple experiences occurring during the day and how it generates new representations during sleep.

"You can envision this experiment as an analog for what humans would experience when spending a long day exploring 15 avenues in a new city across the day, with several 1-2 h-long resting epochs in between," George Dragoi, co-author of the paper, told MedicalXpress.

"In this scenario, what do people remember at the end of the day, how is what happened on each avenue being kept separated from what happened on the other ones without a major interference, and how is the overall experience of the day being organized at the whole day resolution, in addition to the detailed experience on each avenue (e.g., the order in which the avenues were visited)?"

To investigate the neural processes involved in the replay and pre-play of sequential experiences during sleep, Dragoi and his colleagues carried out a series of experiments involving freely moving rats. These rats were placed on 15 linear tracks and were allowed to freely explore these tracks.

The team recorded the activity of neuronal ensembles in the animals' hippocampus throughout their track exploration. They also recorded the activity of these neurons during sleep, in sessions before, in between and after the exploration of tracks.

"We recorded this activity at the millisecond timescale resolution from 128 recording channels," Dragoi explained.

"This time resolution is critical to identify the highly time-compressed offline representations during sleep and particularly the fine dynamics of multiplexed flickering representations of two or more experiences within the same event.

"I also think that the physical exploration of linear tracks (as opposed to virtual reality environments, which are currently used at many laboratories) provides the unique opportunity for the animals to be engaged in truly distinct multi-sensory contextual experiences."

The experiments carried out by Dragoi and his colleagues gathered some interesting observations. For instance, the team found that the rats' earliest and most recent experiences during the exploration were more frequently represented in the hippocampus.

While sleeping rats replayed past experiences or pre-played future ones, different experiences were co-represented following specific patterns, which increased their brain's capacity for representations. Moreover, pairs of explored tracks that were close to each other appeared to be connected, producing continuous representations.

Finally, the overall sequence in which the rats had explored the tracks during the day appeared to be re-played in the brain during sleep at hyper-compressed ratios.

"Our findings reveal the large capacity of the brain to process numerous experiences without major interference, particularly by the fast-paced multiplexing of two or more parallel representations," Dragoi said. "In addition, they outline the principles by which representations of multiple experiences can combine in a generative and multiplex manner to result in apparently new representations based on prior knowledge."

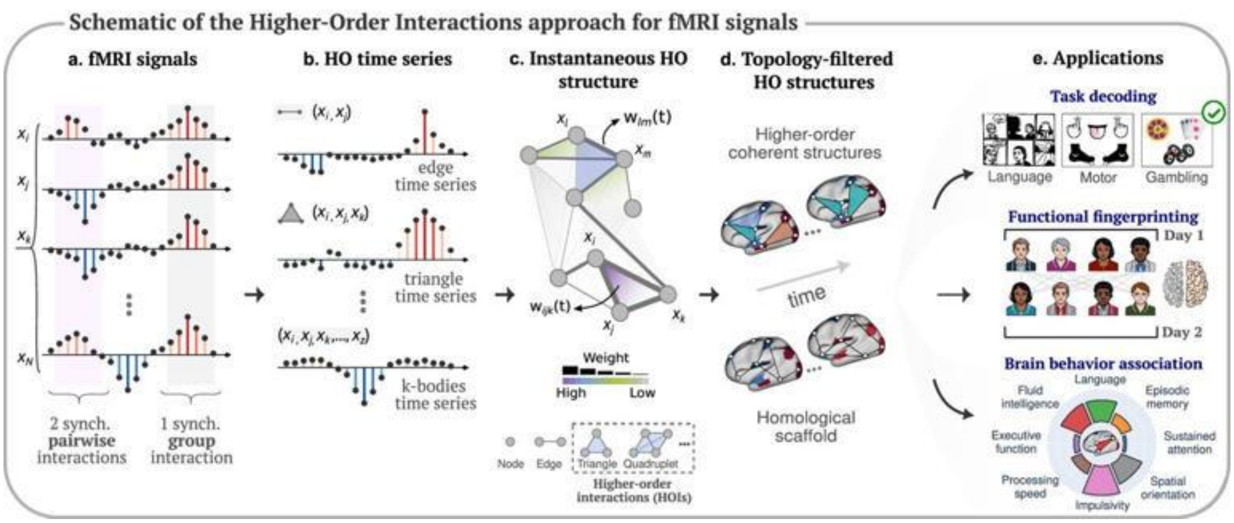
The recent study by Dragoi and his colleagues greatly contributes to the understanding of how the rat brain replays past sequential experiences and uses them to create representations of future experiences during sleep. In the future, these researchers' findings could pave the way for further research aimed at further investigating the readout of the processes they uncovered.

"A most surprising and intriguing finding for us was the hyper-compressed representation of multiple experiences spread across a whole day of an animal, in the order in which they occurred within sub-second flashes of higher order sequential reactivation, an index of experiences of that day" Dragoi added.

"We would now like to better understand the readout of the hippocampal computations by the downstream areas, or in other words, how the parallelization on the one hand and binding on the other hand of multiple information processing in the hippocampus impact functionally connected downstream areas."

More information: Kefei Liu et al, Nested compressed co-representations of multiple sequential experiences during sleep, *Nature Neuroscience* (2024). DOI: 10.1038/s41593-024-01703-6.

Brain mapping technique reveals insights into brain's higher functions



Higher-order brain mapping: schematic of the approach and applications. Credit: Nature Communications (2024). DOI: 10.1038/s41467-024-54472-y

A new way of mapping activity and connections between different regions of the brain has revealed fresh insights into how higher-order functions like language, thought and attention, are organized.

Traditional models of human brain activity represent interactions in pairs between two different brain regions. This is because modeling methods have not developed sufficiently to describe more complex interactions between multiple regions.

A new approach, developed by researchers at the University of Birmingham is capable of taking signals measured through neuroimaging, and creating accurate models from these to show how different brain regions are contributing to specific functions and behaviors. The results are published in *Nature Communications*.

Lead researcher, Dr. Enrico Amico, said, "Complex systems like the brain depend on interactions between groups of regions, not just between pairs of regions. Although we know—in theory—that this is the case, until now we have not had the processing power required to model this."

In the study, the group used data from fMRI scans recorded as part of the Human Connectome Project. This large-scale research consortium was set up to map the human brain, connecting its structure to function and behavior.

These scans, however, can provide only "noisy" estimates of neural activity, so statistical methods are needed to clean up the data and compile accurate estimates of interactions from the neuroimaging signals.

Taking 100 unrelated subjects from the projects' databank, the team produced detailed models of higher-order interactions. They tested these in three key areas, designed to test how useful the approach is.

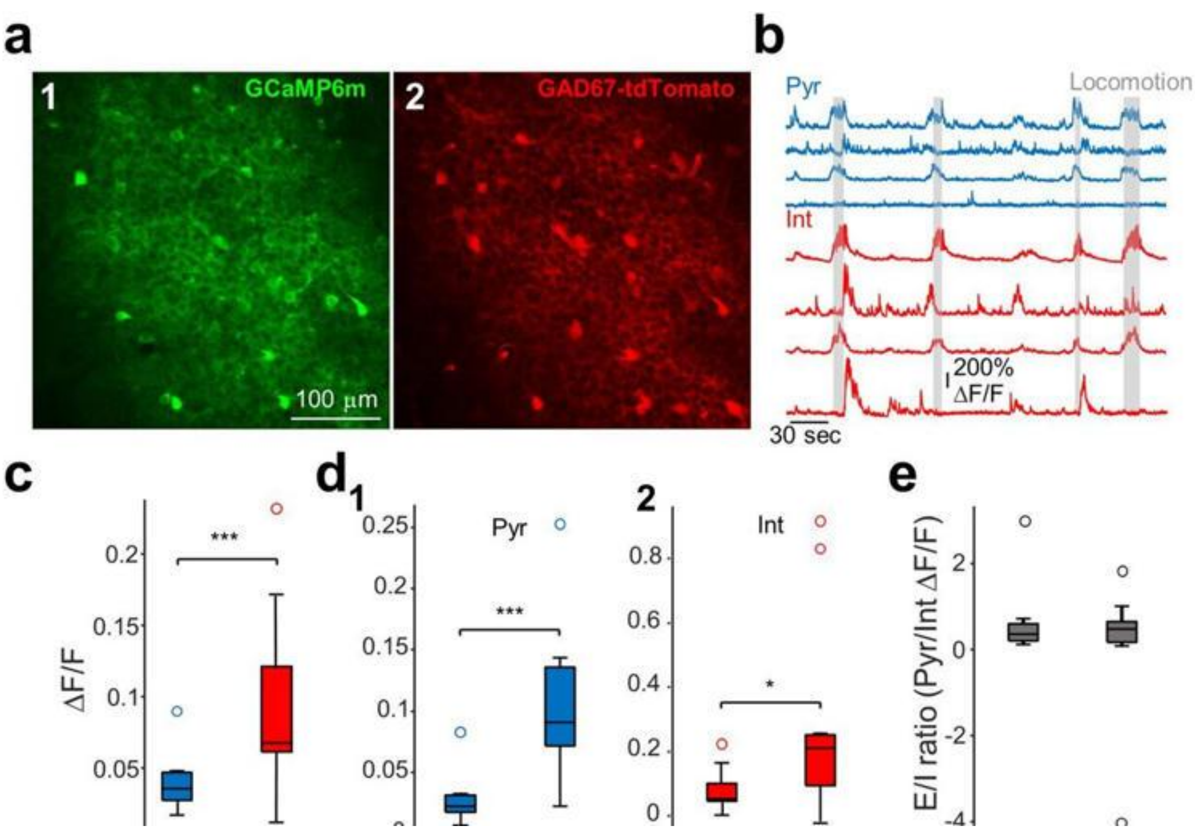
In the first, they were able to show it was possible to identify what task the individual might have been doing while in the fMRI scanner. In the second area of research, the team showed it was possible to identify a specific individual from their brain signals—using the signals as a sort of unique brain fingerprint for the individual. And in the third area, the researchers demonstrated how higher order brain signals of an individual could be separated out from the lower order signals, and how they can be associated with the behavioral features of each individual.

Dr. Andrea Santoro, of the CENTAI Institute in Italy, is the first author of the paper. He said, "Our approach, validated using data from healthy individuals, demonstrates the substantial advantages that this method can offer to neuroscience research. In the future, this method could also be used to help model interactions in individuals with neurodegenerative diseases, such as Alzheimer's, where they could give valuable insights into how brain function is changing over time, or even to identify pre-clinical symptoms of these conditions."

More information: Andrea Santoro et al, Higher-order connectomics of human brain function reveals local topological signatures of task decoding, individual identification, and behavior, *Nature Communications* (2024). DOI: 10.1038/s41467-024-54472-y

Provided by University of Birmingham

Scientists reveal how brain cells called interneurons act as traffic controllers



CA1 interneuron activity is linked to pyramidal cell synchrony. Credit: PLOS Biology (2024). DOI: 10.1371/journal.pbio.3002837

A study led by Dr. Marco Bocchio in the Durham University Department of Psychology reveals how specific brain cells called interneurons can act as our in-built traffic controllers. The findings are published in the journal *PLOS Biology*.

The research opens up potential future treatments for neurological disorders by understanding how these brain cells communicate. Until now, it was unclear how individual interneurons contribute to larger patterns of brain activity.

Interneurons work a bit like the brain's traffic controllers where they regulate the firing of other brain cells, acting like a sophisticated brake system. This control is critical because when interneurons behave differently, it can contribute to neurological conditions like epilepsy, autism, and schizophrenia.

The team studied interneurons in mice and looked at a brain region crucial for learning and memory within the hippocampus. They used advanced brain imaging and light-activated cell techniques.

During quiet, restful periods, they found that activating a single interneuron triggered a coordinated response across other brain cells—a short burst of synchronized brain activity. This happened without disturbing the existing organization of the brain cells.

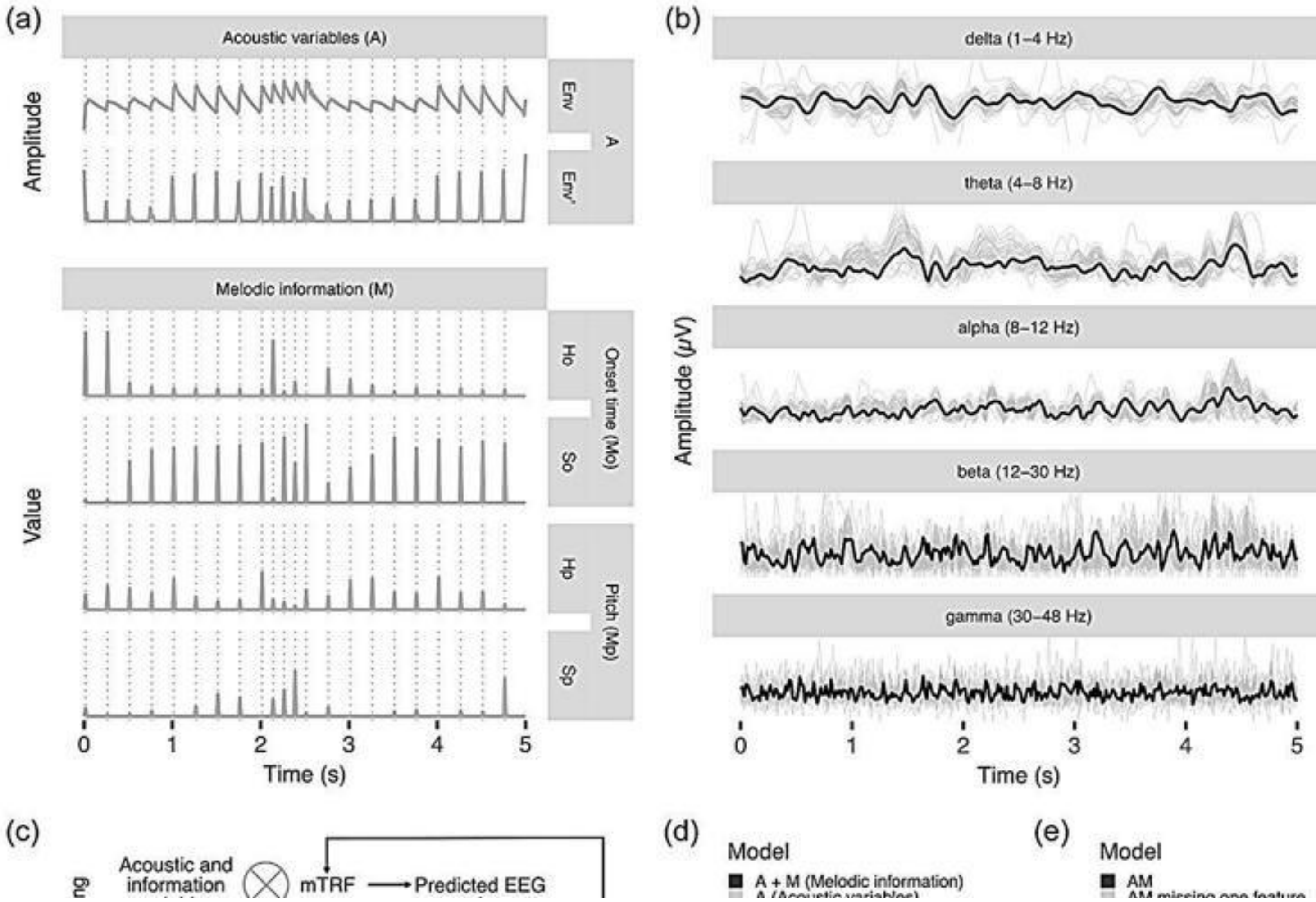
Activating a single interneuron weakened the brain's "stop" signals which then allowed groups of brain cells to fire together. These synchronized brain cell activities might help with forming new memories or processing past experiences.

This discovery offers valuable insights into how our brain is organized and suggests that targeting interneurons could one day help treat disorders linked to pathological brain rhythms.

More information: Marco Bocchio et al, Functional networks of inhibitory neurons orchestrate synchrony in the hippocampus, *PLOS Biology* (2024). DOI: 10.1371/journal.pbio.3002837

Provided by Durham University

Study explores how brain waves reflect melody predictions while listening to music



A, Snippet of the sets of regressors obtained from one piece of music used to calculate the TRFs. From top to bottom: acoustic envelope (Env), half-way rectified first derivative of the envelope (Env'); melodic information for note onset (Mo): onset entropy (Ho), onset surprisal (So); melodic information for note pitch (Mp): pitch entropy (Hp), and pitch surprisal (Sp). Based on Di Liberto, Pelofi, Bianco, et al. (2020). B, Snippet of pre-processed EEG bands of a single subject used for TRF analysis. Gray lines represent individual channels and black lines represent the average amplitude across electrodes for each frequency band. C, Schematic of the pipeline. Melodic information features were extracted with IDyOM (Di Liberto et al., 2021; Pearce, 2005). Separate multivariate temporal response function (mTRF) models were trained from the preprocessed EEG signal and the acoustic and melodic information features (see Materials and methods). The sets of features were convolved with the corresponding optimal TRFs to predict the EEG signals. The reconstruction accuracy is calculated as the Pearson correlation between the original filtered EEG and the predicted one. D, Hypothetical enhancement in EEG reconstruction accuracy of a model trained on acoustic and melodic information variables (AM) compared to a model trained only on acoustic regressors. Based on Di Liberto, Pelofi, Bianco, et al. (2020). E, Hypothetical unique contribution of an individual feature to the full model, measured as the difference in the Pearson correlation between the reconstruction accuracy obtained using the AM model and the same model missing one specific feature. Credit: European Journal of Neuroscience (2024). DOI: 10.1111/ejn.16581

The human brain is highly skilled at detecting patterns in the world and using this information to predict future events. This ability to anticipate events is also reflected in how we experience music, precisely in our ability to intuitively anticipate what will come next in a melody we are listening to.

Researchers at the Max Planck Institute for Human Cognitive and Brain Sciences have been trying to better understand the complex neural dynamics underpinning this ability to predict upcoming melodies in music. Their most recent paper, published in the *European Journal of Neuroscience*, shows that uncertainty (i.e., entropy) plays a key role in melody prediction, while also highlighting new differences in how the brains of musicians and non-musicians process music.

"Prior work on music cognition suggests that low-frequency (1–8 Hz) brain activity encodes melodic predictions beyond the stimulus acoustics," wrote Juan-Daniel Galeano-Otálvaro, Jordi Martorell and their colleagues in their paper. "Building on this work, we aimed to disentangle the frequency-specific neural dynamics linked to melodic prediction uncertainty (modeled as entropy) and prediction error (modeled as surprisal) for temporal (note onset) and content (note pitch) information."

For the purpose of their study, the researchers recruited 20 participants, half of whom were professional pianists. These participants were asked to listen to 10 piano melodies extracted from the work of Johann Sebastian Bach, each lasting approximately 150 seconds.

The participants listened to each of these melodies three times. While they were listening, the researchers collected recordings using electroencephalography (EEG), a technique that relies on electrodes to measure the brain's electrical activity.

The team calculated the probability of specific notes following others in a sequence and this allowed them to compute the surprisal that segments of a melody would typically elicit. They then separately computed entropy, a measure of uncertainty, as the average of surprisal over all continuations in a note sequence.

Galeano-Otálvaro and his colleagues analyzed the participants' EEG recordings using different software toolkits for scientific research, including MATLAB, the FieldTrip toolbox and the EEGLAB toolbox. Their analyses unveiled neural correlates of melody prediction while listening to music.

"Our results show that melodic expectation metrics improve the EEG reconstruction accuracy in all frequency bands below the gamma range (< 30 Hz)," wrote the researchers. "Crucially, we found that entropy contributed more strongly to the reconstruction accuracy enhancement compared to surprisal in all frequency bands. Additionally, we found that the encoding of temporal, but not content, information metrics was not limited to low frequencies, rather it extended to higher frequencies (> 8 Hz)."

Overall, the researchers found that uncertainty (i.e., entropy) in melody is encoded in neural responses that range across different frequency bands. The researchers were also able to pinpoint the frequencies that could encode uncertainty about the onset of notes before the participants heard a given note.

"An analysis of the temporal response function (TRF) weights revealed that the temporal predictability of a note (entropy of note onset) may be encoded in the delta- (1–4 Hz) and beta-band (12–30 Hz) brain activity prior to the stimulus, suggesting that these frequency bands associate with temporal predictions," wrote the researchers.

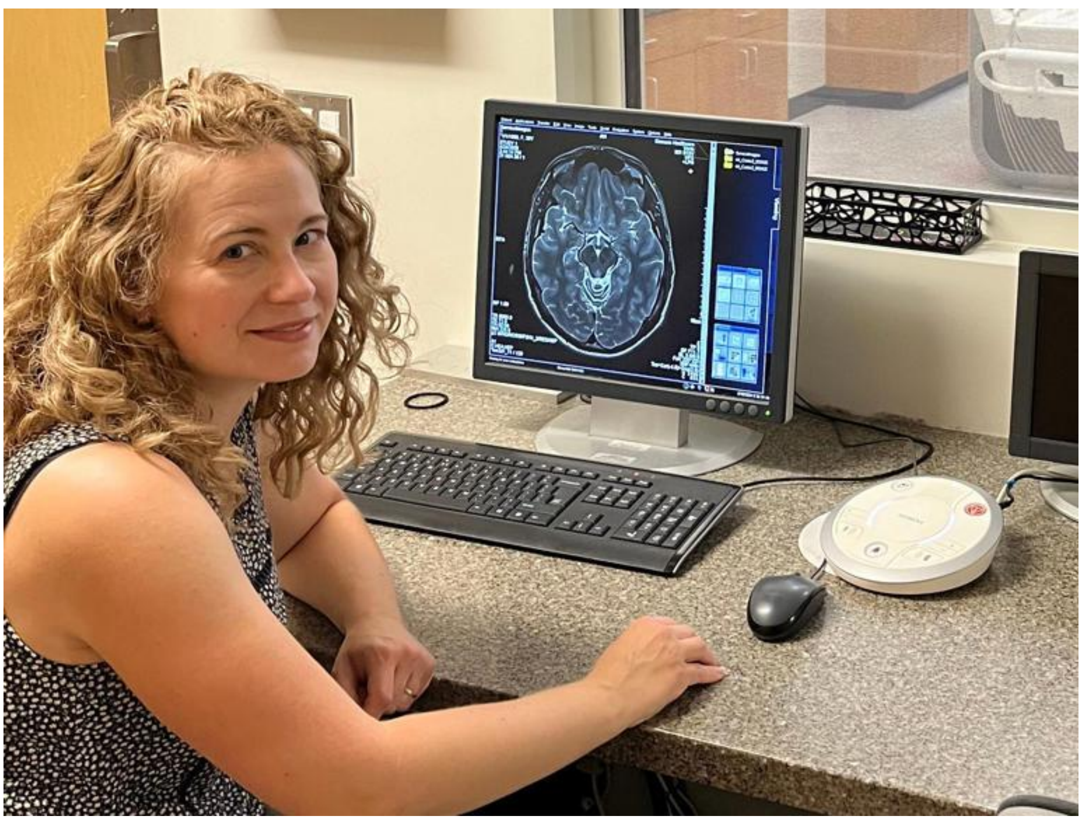
"Strikingly, we also revealed that melodic expectations selectively enhanced EEG reconstruction accuracy in the beta band for musicians, and in the alpha band (8–12 Hz) for non-musicians, suggesting that musical expertise influences the neural dynamics underlying predictive processing in music cognition."

In addition to gathering insight about the brain activity underpinning melody prediction while listening to music, the researchers observed differences between the electrical activity in the brain of professional pianists and non-musicians. Specifically, they found that melody predictions correlated with more brain waves in the beta frequency band for pianists and in the alpha band for non-musicians

The team's interesting results could soon pave the way for new studies exploring the neural correlates of melody prediction or the differences observed between musicians and non-musicians. These works could further enrich the present understanding of how the human brain processes music and predicts upcoming events.

More information: Juan-Daniel Galeano-Otálvaro et al, Neural encoding of melodic expectations in music across EEG frequency bands. *European Journal of Neuroscience*(2024). DOI: 10.1111/ejn.16581

Groundbreaking brain scans explain the 'mommy brain' phenomenon



Liz Chrastil looking at an MRI of her brain. Liz Chrastil© Liz Chrastil

- Little is known about how brains change throughout pregnancy, birth, and postpartum.

- A neuroscientist scanned her own brain during pregnancy to track its changes.
- She lost gray matter and improved connectivity via white matter.

For how common the phrase "mommy brain" is, we still don't know much about how pregnancy, birth, and postpartum alter a person's brain.

"It's shocking that in 2024, there's so little information available to us," Dr. Liz Chrastil, 43, a neuroscientist and associate professor at UC Irvine, told Business Insider.

It's what inspired her to scan her own brain when she was pregnant at 38.

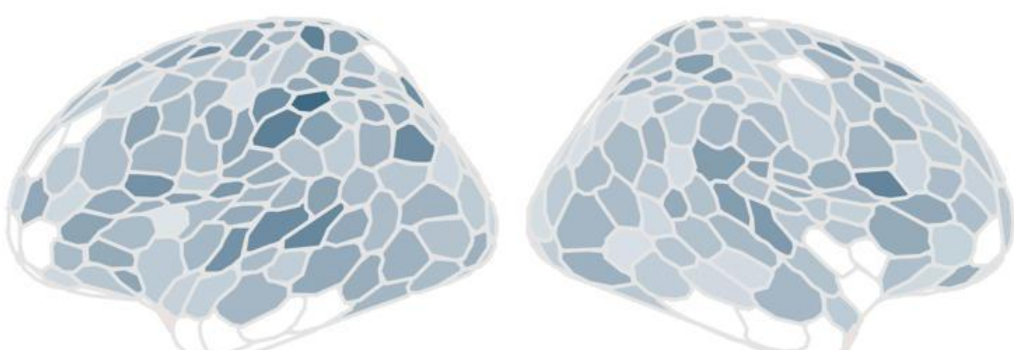
With the help of a team of researchers, Chrastil underwent 26 MRIs, spread out between three weeks before she conceived and two years postpartum. The results were published in Nature Neuroscience on Monday.

Her team noticed structural changes in her brain, such as a reduction in gray matter and an increase in white matter, some lasting up to two years after giving birth. Still, "this study brings up more questions than it answers," Chrastil said.

"We think that these have some beneficial use to them, but we don't necessarily know what they are," she added. "It might be useful to the mother to be able to have better bonding or caregiving to the infant."

While she said more research is needed to understand these changes, the study reveals just how profound pregnancy and postpartum are to brain development.

She lost gray matter in most parts of her brain



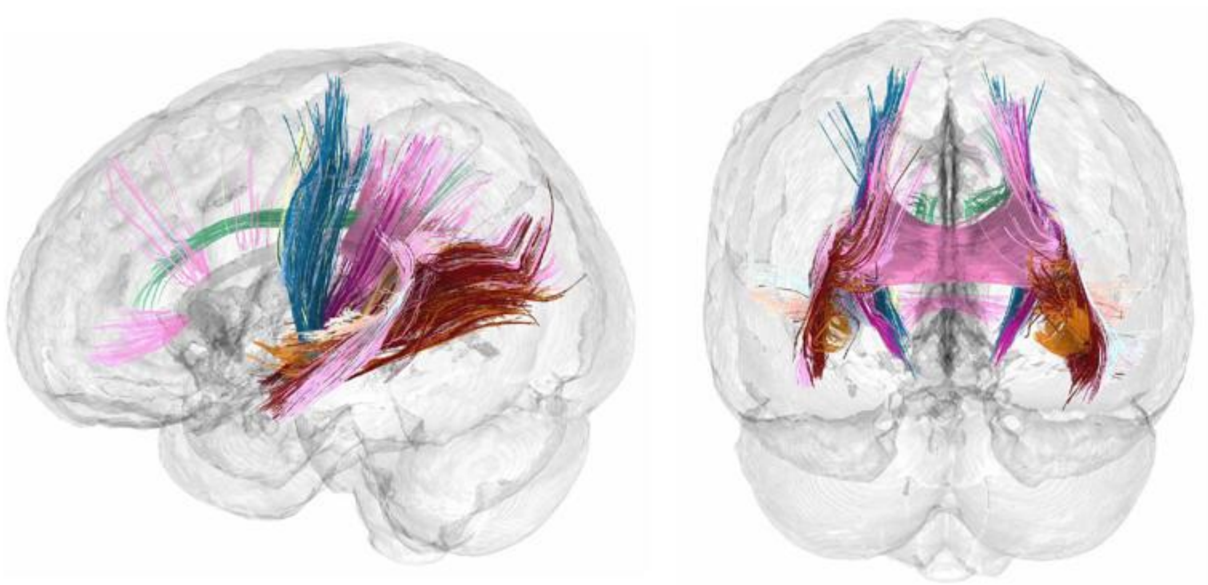
The regions of Chrastil's brain impacted by gray matter changes. Nature Neuroscience© Nature Neuroscience

In the brain, gray matter refers to areas with large concentrations of neurons and plays a huge role in cognitive and emotional functioning.

Chrastil said about 80% of the regions in her brain experienced a decrease in gray matter, averaging a 4% decrease. The findings were consistent with past studies on gray matter reduction during pregnancy, which can last up to two years postpartum.

Reduced gray matter is associated with health risks like depression. While Chrastil "didn't feel too bad" during pregnancy, she said further studies with more participants could help with treating conditions like postpartum depression.

Her brain increased connectivity



A diagram of the white matter tracts in Chrastil's brain. Nature Neuroscience© Nature Neuroscience

Chrastil was most surprised by the improved connectivity in her brain, which peaked during the second and third trimesters and "returned back to baseline" after birth.

"We had no idea that that was going to be there," she said. White matter, the parts of brain cells that connect to other neurons in fiber bundles, is linked to improved learning and focus.

Chrastil and her team purposefully didn't look at the data while she was undergoing the study, so as not to influence their findings. Still, she felt some subtle changes.

"I certainly felt sort of ready at that point to become a mother," she said. "That sort of readiness feeling might be part of it."

The changes weren't permanent

The reason Chrastil continued to get scans for two years postpartum was to track the long-term stability of her brain's changes.

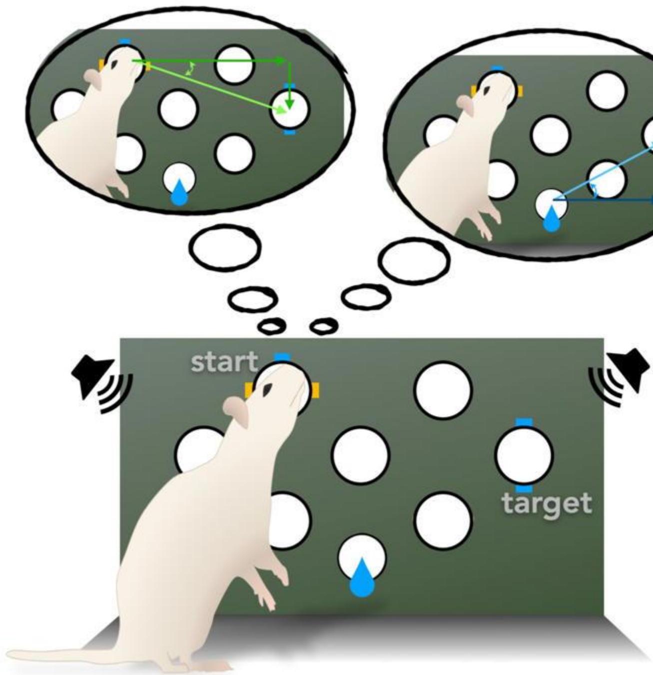
"There's this huge increase in sex hormones over the pregnancy and then it comes crashing down," she said. "Boom, everything returns back."

Liz Chrastil with her child. Liz Chrastil© Liz Chrastil

She hopes that more research will uncover the purpose of all these changes, such as how white matter changes influence maternal care and preparedness.

"We really need more people to be able to answer that question," she said.

Navigating space: Dual maps discovered in the brain



As a rat plans to move from a start position to a target, it can consider the location of the target in "world" coordinates (shown as the target in relation to the reward port with blue vectors) or in "self" coordinates (shown as the target in relation to the current position of the rat at the start port, with green vectors). Researchers found that the self-centered representation dominated during the planning period. Credit: Sainsbury Wellcome Centre

In the brain's secondary motor cortex, researchers have discovered two distinct maps that play a crucial role in spatial planning and navigation. The research, led by Dr. Jeffrey Erlich, Group Leader at the Sainsbury Wellcome Centre at UCL, provides a new approach to studying spatial planning in rodents, and could have implications for understanding neurological conditions that affect spatial attention, such as stroke.

"We discovered that the premotor cortex uses a self-centered coordinate system for spatial planning, but that it also encodes a world-centered map that is used for determining the body's current position in the world. This self-centered and world-centered information is combined in individual neurons in a multiplicative way, which makes it easier to disentangle downstream," explained Dr. Erlich, corresponding author on the study.

The study, published in the *Journal of Neuroscience*, outlines how the researchers designed a novel task in rats that allowed them to differentiate between self-centered and world-centered reference frames. They recorded neural activity from an area of the brain known as the frontal orienting field (FOF) in the secondary motor cortex in rats and used machine learning techniques to decode the information.

"Imagine being asked where the nearest coffee shop is. You could say 'walk forward and turn left' (self-centered directions) or 'walk north, then east' (world-centered directions). We want to understand how the brain transitions between these reference frames and transforms them into action," explained Dr. Erlich.

The researchers developed a task involving a wall with seven portholes. Rats were trained to place their nose into a starting porthole, after which a light would appear in another porthole, designating it as the target. The rats then had to wait for an auditory cue before moving their nose to the target porthole to receive a reward. This waiting period allowed the researchers to distinguish between planning and action in the brain.

"By adding the right amount of complexity to our task, we were able to have good experimental control over the timings. This approach allowed us to tease apart the different dimensions of representation," explained Dr. Erlich.

Some trials had different movement directions that led to the same target, and some had the same movement direction but led to different targets as they had different starting points. The researchers examined the neural activity during the period in between the visual and auditory cues, to establish whether the brain was planning based on the direction or final position, thereby determining if the FOF was using a self-centered or world-centered map.

"We were surprised to find a world-centered map in FOF as this has never been reported before. We want to explore what this position information is being used for and under what circumstances it becomes functionally relevant," concluded Dr. Erlich.

The team is now exploring how these dual maps are used in tasks where the instructions are given in world-centered coordinates. They are also studying how the brain plans more complex sequences of movements. The ultimate goal of this research is to further understand the fundamental principles of spatial attention and how attention is linked to planning and execution of orienting movements. This has potential implications for neurological conditions such as hemispatial neglect following a stroke, where people cannot process or shift attention to one part of the world.

More information: Liujunli Li et al, Encoding of 2D Self-Centered Plans and World-Centered Positions in the Rat Frontal Orienting Field, *The Journal of Neuroscience* (2024). DOI: 10.1523/JNEUROSCI.0018-24.2024

Provided by Sainsbury Wellcome Centre

Brain Waves Can Be Manipulated While We Dream, And It Could Help Treat Dementia

Sleeping person

Scientists in the UK have manipulated two prominant types of brain wave while volunteers slept, in an effort to develop better tools to study critical neurological activities.

The waves, referred to as alpha and theta oscillations, are strongly associated with resting and relaxing states, including the Rapid Eye Movement (REM) stage of unconsciousness.

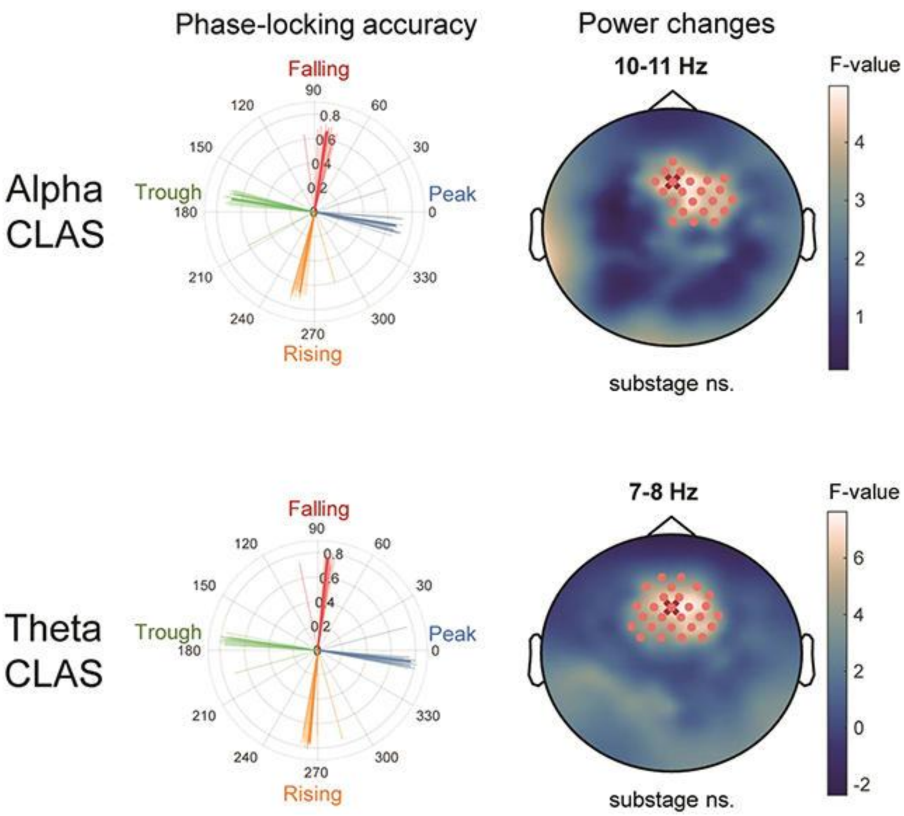
Named for the jerking motion of our eyes while in this stage of sleep, REM coincides with the appearance of our most vivid dreams. The stage is also considered to play an important role in memory consolidation and honing cognition, making any brain wave activity an attractive target for scientists.

"Brain oscillations assist in the working of the brain and how it learns and retains information," says neuroscientist Valeria Jaramillo, from the University of Surrey.

"Brain oscillations during REM sleep have been implicated in memory functions – however, their exact role remains largely unclear."

A process called closed-loop auditory stimulation (CLAS) has been successfully used to enhance or disrupt brain waves in non-REM sleep, precisely targeting the ebb and flow of brain waves via sounds delivered through headphones.

The process had rarely been applied to sleepers outside of this state, so researchers from the University of Surrey tested the method on volunteers to determine if it might also apply to waves produced during REM.



Sounds were used to target different types of oscillations. (Jaramillo et al., SLEEP , 2024)

In tests involving 18 participants, the researchers changed both the speed and strength of the brain waves as measured through electrodes on the skull.

Alpha (around 8 to 12 Hertz) and theta (around 4 to 8 Hertz) oscillations typically flow through the brain's frontal region while we're in a relaxed state, such as when we're dozing or deciding whether to get out of bed to start the day.

In fact, these brain waves are pretty similar whether we're awake or in REM sleep. We know that brain waves, pulses of electrical activity triggered by neurons, help in the healthy functioning of the brain. If we can control them to an extent, that's potentially helpful in making sure the brain is working as it should – and in slowing the rate of degeneration associated with dementia.

"Using sound stimulation to change brain oscillations whilst a person sleeps shows therapeutic promise," says University of Surrey neuroscientist Ines Violante.

"There is currently no cure for dementia, only medication that can slow down disease progression or temporarily help a person with their symptoms, so it is important that we think innovatively to develop new treatment options."

A lot more research will be needed to show this can actually have a therapeutic effect on dementia, but scientists have already shown that the symptoms of dementia – trouble with memory and cognitive abilities – often coincide with the slowing of brain wave oscillations, which is something we might now be able to influence.

"This could pave the way for a new approach on how to treat patients with dementia, as the technique is non-invasive and undertaken whilst they are asleep, lessening the disruption to their lives and enabling us to be more targeted in our approach," says Derk-Jan Dijk, a professor of sleep and physiology at the University of Surrey.

The research has been published in *SLEEP*.

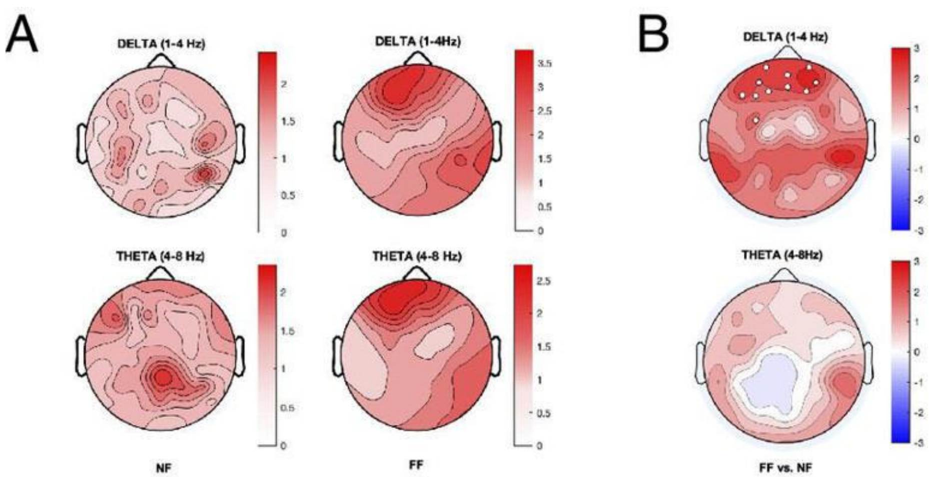
Mental fatigue leads to loss of self-control and poor decision-making

Social interactions often demand a delicate balance of self-control and rational decision-making. However, new research suggests that mental fatigue—whether from prolonged cognitive tasks or sleep deprivation—can disrupt this balance, leading to impulsive and sometimes aggressive behavior.

A study published in PNAS by a multidisciplinary team from the IMT School for Advanced Studies Lucca and the University of Florence investigates how short-term cognitive exhaustion manifests in brain activity and impacts socially relevant decisions.

Cognitive Fatigue and the Struggle for Self-Control

The concept of “ego depletion” has long intrigued psychologists and behavioral economists. This theory posits that self-control is a finite resource, one that diminishes with use. Tasks requiring high levels of focus, emotional regulation, or decision-making deplete your cognitive reserves, leaving you more prone to impulsive actions.



Panel shows low-frequency EEG activity changes associated with the FF and NF experimental conditions. (CREDIT: PNAS)© The Brighter Side of News

Behavioral experiments often test ego depletion using tasks like the Stroop test or emotion suppression exercises. Participants engage in cognitively demanding tasks and then complete subsequent exercises requiring self-control. The result? A reduced ability to act altruistically, increased selfishness, and a greater likelihood of aggression.

Despite its intuitive appeal, the ego depletion hypothesis has faced criticism. Some studies have struggled to replicate its effects consistently, leading to questions about its validity. Yet, as Pietro Pietrini, director of the Molecular Mind Lab at IMT, notes, the effect might lie on a spectrum, influenced by the intensity and duration of cognitive tasks.

Bridging Economics and Neuroscience

In a groundbreaking effort to resolve these inconsistencies, the study combines behavioral economics with neuroscience. The researchers hypothesized that ego depletion has a physiological basis: mental fatigue triggers sleep-like brain activity, even while you're awake. This "local sleep" involves slow delta waves in the frontal cortex, a region critical for executive functions like decision-making and impulse control.

Related Stories

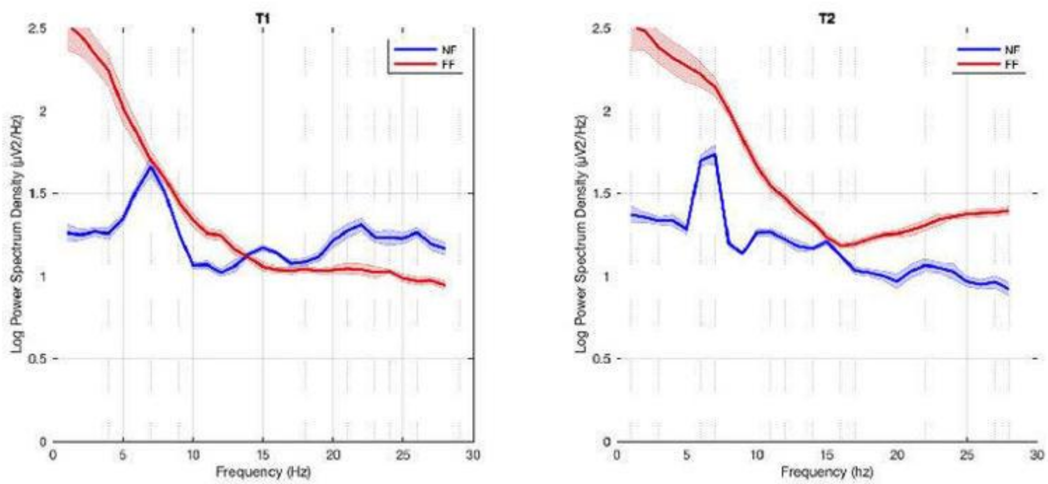
Common cholesterol drug slows mental decline from Alzheimer's disease Just 20 seconds of this activity can significantly reduce stress and boost mental health Arts and crafts can improve mental health and well-being, study finds

“Our starting hypothesis was that local sleep would be the neuronal manifestation of the ego depletion phenomenon,” says Erica Ordali, lead author of the study.

To test this, researchers designed a more rigorous experimental setup. Unlike previous studies that relied on short, 15-minute tasks, this study subjected participants to an hour-long cognitive fatigue task. The goal was to induce a more pronounced state of mental exhaustion, providing a clearer test of the ego depletion effect.

Economic Games Reveal Behavioral Shifts

Following the fatigue task, participants engaged in a series of economic games designed to measure social behavior. One key game was the "hawk and dove" game, which simulates resource competition in hostile environments. Players must choose between cooperation (dove) or aggression (hawk), with mutual aggression often leading to resource loss for both parties.



The Left plot shows the change in PSD in the NF group (blue) and in the FF group (red) after T1, while the Right plot shows the PSD difference after subjects performed the EG (T2). (CREDIT: PNAS)© The Brighter Side of News

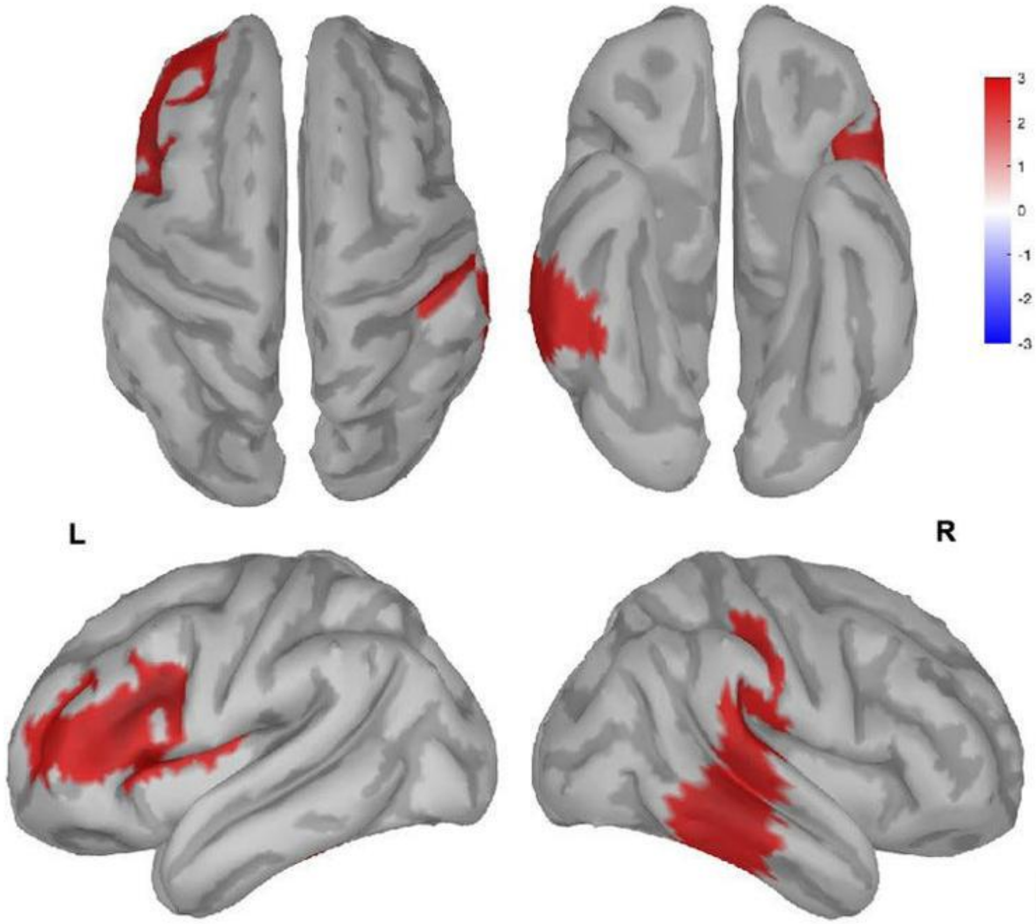
The results were striking. Participants who underwent the fatigue task were significantly less cooperative, with peaceful cooperation rates dropping from 86% in the non-fatigued group to just 41% among the fatigued participants. This dramatic shift highlights how cognitive exhaustion can impair social decision-making.

But the behavioral data was just the beginning. To gain deeper insights, all participants wore electroencephalogram (EEG) caps during the games. In the fatigued group, researchers observed a clear emergence of sleep-like delta waves in the frontal cortex. These waves, typically associated with deep sleep, were absent in the non-fatigued group.

“These findings show that mental fatigue has a measurable effect on behavior,” Ordali explains. “When fatigue sets in, individuals are more likely to act aggressively.”

The Role of Local Sleep in Decision-Making

The study provides a compelling neural explanation for the behavioral changes observed. Local sleep, characterized by delta wave activity in specific brain regions, appears to be the brain's response to prolonged cognitive effort. These waves signal that the affected areas, such as the frontal cortex, are effectively “offline,” impairing their ability to regulate behavior.



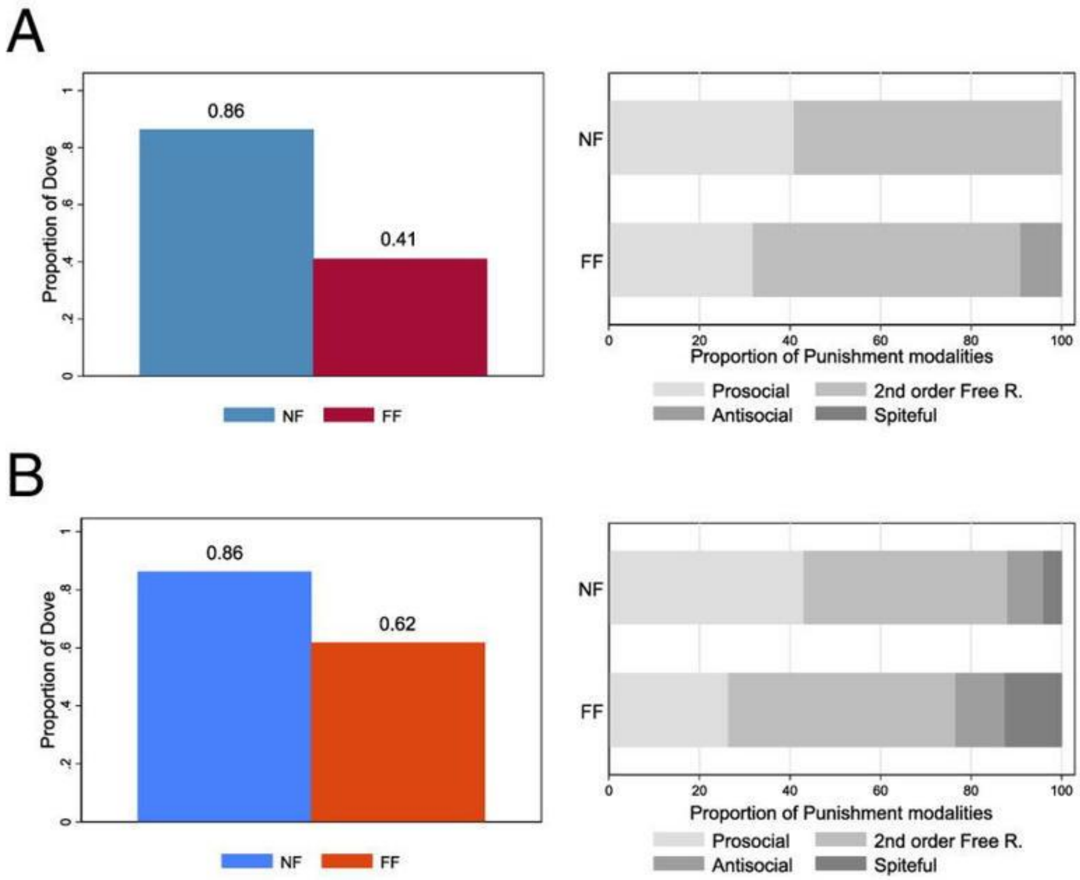
Source analysis of the delta EEG activity associated with the FF condition. Significant differences (P 0.01, cluster-based correction) in T1/T0 delta ratios between FF and NF. Specifically, difference peaks were found in the left IFG (−36, 16, 28) and in the right middle temporal lobe (70, −30, −2). (CREDIT: PNAS)© The Brighter Side of News

Interestingly, this phenomenon is not limited to extreme conditions like sleep deprivation. The study shows that even moderate cognitive strain can trigger local sleep, underscoring how sensitive the brain is to fatigue.

"In animal models, we've seen similar slow-wave activity during periods of intense mental effort," Pietrini notes. "Our study extends this understanding to humans, showing how task-induced neural fatigue impacts social interactions."

Broader Implications

The implications of these findings extend beyond the laboratory. Everyday decisions—whether negotiating contracts, resolving conflicts, or even navigating personal relationships—are often made under conditions of mental strain. Fatigue may lead you to make choices that contradict your long-term interests, sometimes with serious consequences.



Panel (A) shows the results for the Hawk and Dove game and the punishment modalities for Study 1 (N = 44), while panel (B) shows the same results for Study 2 (N = 403). Left panels display the proportion of players who chose the peaceful option in the Hawk and Dove game. (CREDIT: PNAS)© The Brighter Side of News

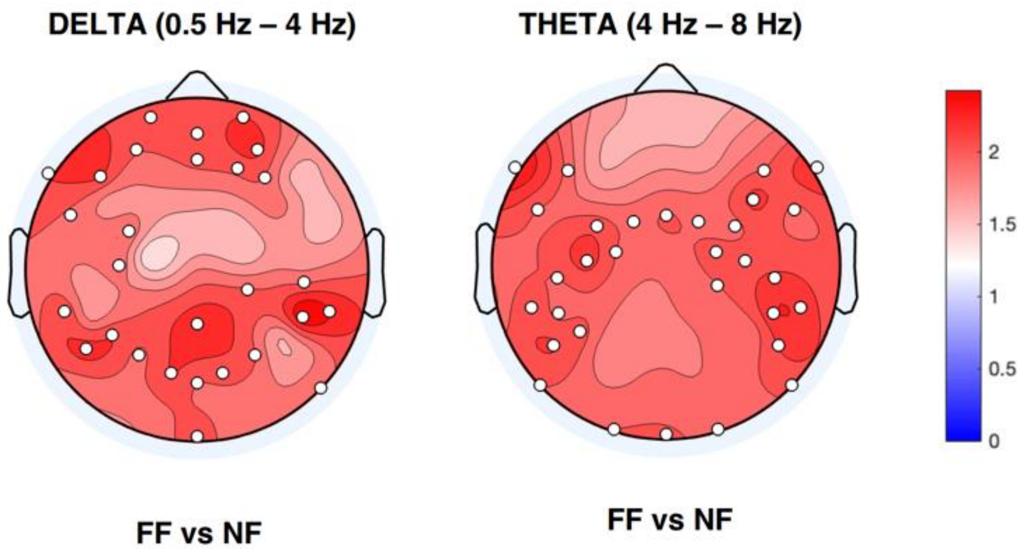
“These results provide scientific backing for the age-old advice to ‘sleep on it’ before making important decisions,” says Pietrini. “They demonstrate how mental exhaustion affects our decision-making processes at a fundamental level.”

The study also sheds light on the potential link between fatigue and criminal behavior. Impulsive, antisocial acts often occur under conditions of mental strain, suggesting that fatigue-induced local sleep might play a role.

“This could explain why many crimes happen when individuals are mentally drained,” Pietrini adds.

Moving Beyond Ego Depletion

While the ego depletion theory has been controversial, this study suggests a more nuanced understanding. Rather than relying solely on psychological models, incorporating neuroscientific data provides a clearer picture of how cognitive fatigue affects behavior. The team’s findings indicate that ego depletion might not be a simple depletion of willpower but a manifestation of neural fatigue, as reflected in sleep-like brain activity.

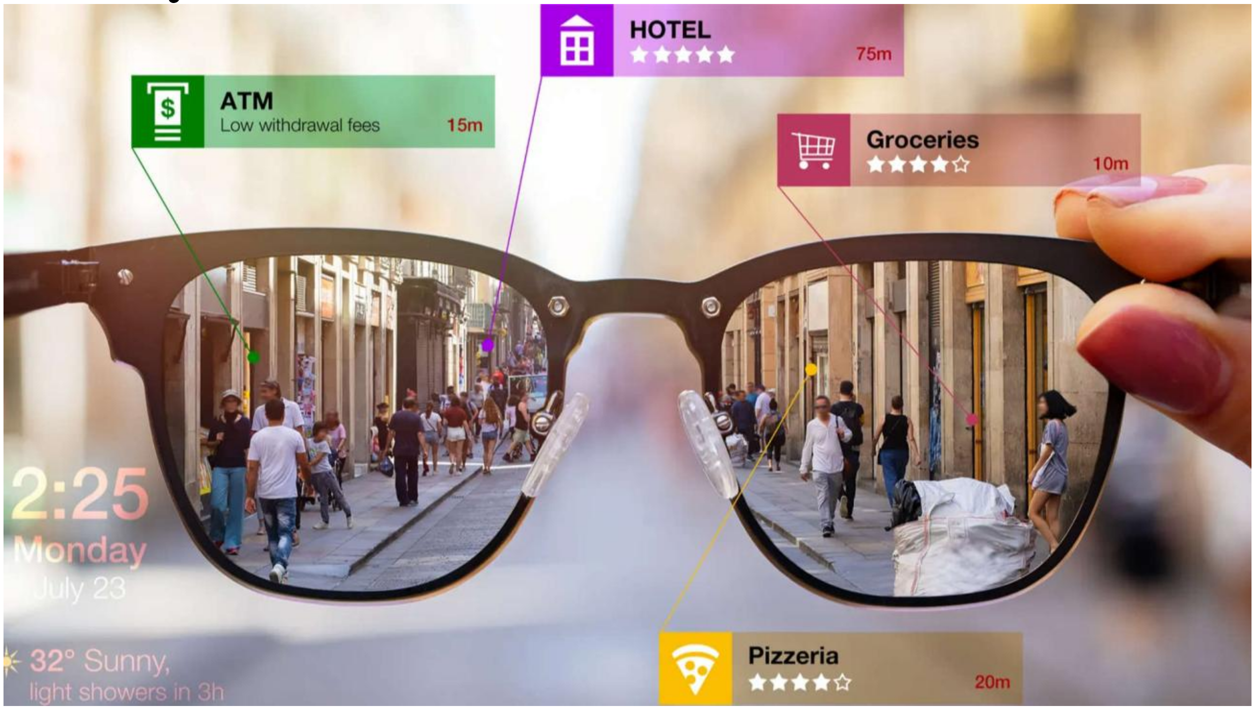


Differences in low-frequency activity variations after T2. The topographic plots show the statistical comparison between experimental conditions (FF vs NF) for delta and theta frequency bands at time T2 after subjects completed the economic games block. (CREDIT: PNAS)© The Brighter Side of News

The study's robust methodology—extending task durations and using EEG monitoring—could pave the way for more reliable investigations into cognitive fatigue. Future research might explore interventions to mitigate these effects, such as short rest periods or techniques to boost cognitive resilience.

This study marks a significant step forward in understanding the complex interplay between mental fatigue, brain activity, and behavior. By highlighting the role of local sleep, it opens new avenues for research and practical applications. Whether in economics, law, or daily life, recognizing the impact of cognitive exhaustion could help individuals and institutions make better decisions.

Apple’s Ambitious Leap into Augmented Reality



The Future of Augmented Reality

Apple might soon wow us with AR glasses featuring cutting-edge MicroLED technology. Imagine sleek glasses that seamlessly blend the digital and real worlds, offering an unmatched visual experience.

Rumors point to a launch as early as 2026, with competitors like Meta gaining ground, so it’s no surprise Apple is working hard to push this project forward. These glasses could mark the start of a new era for wearable technology, one that feels both futuristic and practical.

What Makes MicroLED So Special?

MicroLED combines the best features of OLED and LCD screens, offering incredible brightness, deep blacks, and energy efficiency. It’s a display technology that promises stunning visuals unlike anything we’ve seen.

The challenge? It's extremely difficult and expensive to manufacture, especially for small devices.

If Apple can overcome these hurdles, the AR glasses could outshine competitors in both performance and design.

A Long Journey to Innovation

Apple has been exploring MicroLED tech for years, with whispers of it appearing in devices like the Apple Watch Ultra. This technology could deliver groundbreaking improvements in display quality and energy efficiency.

The road hasn't been easy. High production costs and technical difficulties have slowed progress, but Apple seems determined to bring this innovation to life.

Why 2026 Could Be the Year

Leaked reports suggest Apple's AR glasses may enter production in 2026, signaling a shift in focus toward AR devices. While they might not launch that year, production is a big step forward.

This timeline suggests Apple could be prioritizing these glasses over other rumored projects, like a foldable iPhone. It's clear they're committed to making AR a key part of their future.

Competition Is Heating Up

Meta's Orion AR glasses have sparked a surge of interest in augmented reality. Their success with Ray-Ban Meta smart glasses has shown the potential for wearable tech in everyday life.

Apple seems to be watching closely. To stay ahead, they'll need to deliver a product that's not only innovative but also accessible to a wide audience.

How the Vision Pro Fits In

Apple's Vision Pro headset offers powerful mixed-reality features but comes with a bulky design and a hefty price tag. AR glasses could be the streamlined, affordable alternative consumers are hoping for.

The Vision Pro’s technology might pave the way for more compact, user-friendly AR glasses. Apple seems poised to shrink this innovation into a wearable form.

Could Apple Solve the Power Problem?

AR glasses require powerful chips that won’t quickly drain their battery. While Apple’s current chips, like the M2, deliver impressive performance, they’re not ideal for compact, wearable devices.

By 2026, Apple could design a more efficient processor specifically for ultra-thin AR glasses. This innovation would ensure a perfect balance between high performance and energy efficiency, making the glasses practical and user-friendly for everyday use.

How AR Glasses Could Enhance Daily Tasks

AR glasses have the potential to simplify everyday activities in ways we’ve only imagined. From displaying step-by-step navigation while walking to providing hands-free updates on appointments and reminders, the possibilities are endless.

They could also change the way we shop, offering virtual previews of products or detailed reviews on the go. By blending digital convenience with real-world interactions, AR glasses could become an indispensable tool for modern life.

Apple’s Secret Weapon

Apple’s ecosystem is a major strength, and AR glasses could fit seamlessly into it. Imagine them syncing effortlessly with your iPhone, Apple Watch, and MacBook, enhancing daily tasks and creating a unified digital experience.

This deep integration would make the glasses incredibly intuitive and practical, appealing to anyone already invested in Apple’s devices. It could turn the AR glasses into a must-have addition for loyal Apple users.

Challenges Ahead

The possibilities for AR glasses are limitless. They could transform real-time navigation, enhance video calls, and change how we interact with technology in everyday life.

Gamers, artists, and tech enthusiasts could find new ways to explore creativity and play, while others might use them for more practical tasks. These glasses promise an exciting fusion of the digital and physical worlds, offering something for everyone.

AR Glasses and Everyday Life

The possibilities for AR glasses are limitless. They could transform real-time navigation, enhance video calls, and change how we interact with technology in everyday life.

Gamers, artists, and tech enthusiasts could find new ways to explore creativity and play, while others might use them for more practical tasks. These glasses promise an exciting fusion of the digital and physical worlds, offering something for everyone.

Will They Be Affordable?

Apple’s Vision Pro, priced at $3,500, is beyond the budget of most consumers. AR glasses could bridge the gap, offering advanced features at a more affordable price point.

By introducing a cost-effective option, Apple could appeal to a much broader audience, making AR technology accessible to more people. This move would not only expand Apple’s reach but also help establish AR glasses as a mainstream innovation.

How Meta's Orion Glasses Could Influence Apple

Meta's progress in AR could motivate Apple to accelerate its own innovation. Competition often drives companies to push boundaries, and Meta's success may inspire Apple to aim higher.

To truly stand out, Apple will need to offer something revolutionary. AR glasses featuring advanced MicroLED technology could be the unique solution that sets them apart and captures consumer attention in a competitive market.

Looking Beyond 2026

Even if production starts in 2026, a launch might not happen until 2027 or later. This extra time allows Apple to refine its design and create an unforgettable product.

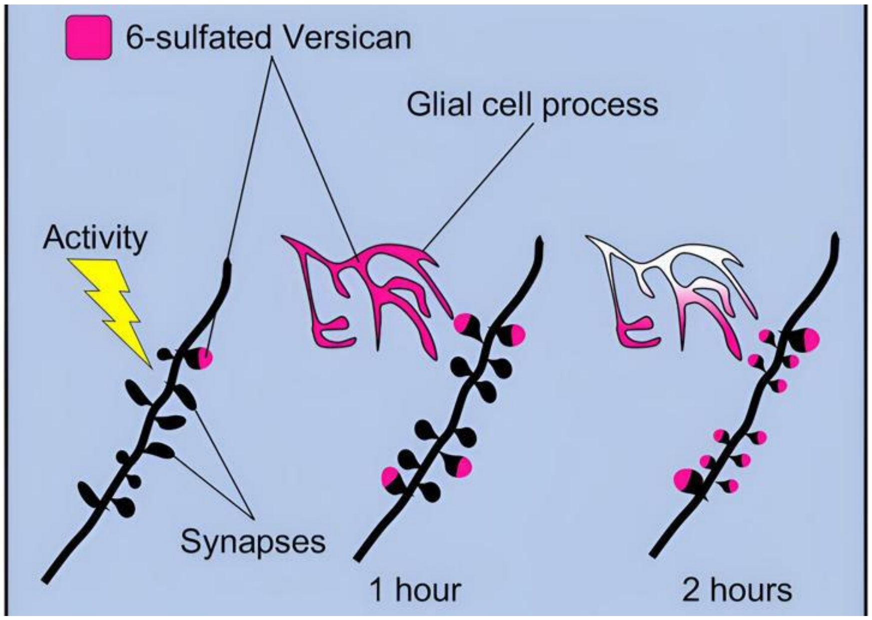
As we wait, advancements like the Vision Pro hint at what Apple might accomplish with AR glasses, offering a glimpse of what's to come.

The Future Is Closer Than You Think

AR glasses have felt like a far-off dream for years, but Apple could bring them to life sooner than we think. The combination of MicroLED and Apple's innovation could redefine wearable tech.

With competition growing and excitement building, one thing is clear: augmented reality glasses are shaping up to be the next big leap in technology.

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



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

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

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

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

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

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

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

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

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

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

"First we went to explore these structures in detail, visualizing them at very high resolution. We found that they are essentially clusters of synapses coated with

CS-6 and organized in a clearly recognizable geometric shape. We then highlighted a new type of synaptic organization," the scholars recount.

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

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

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

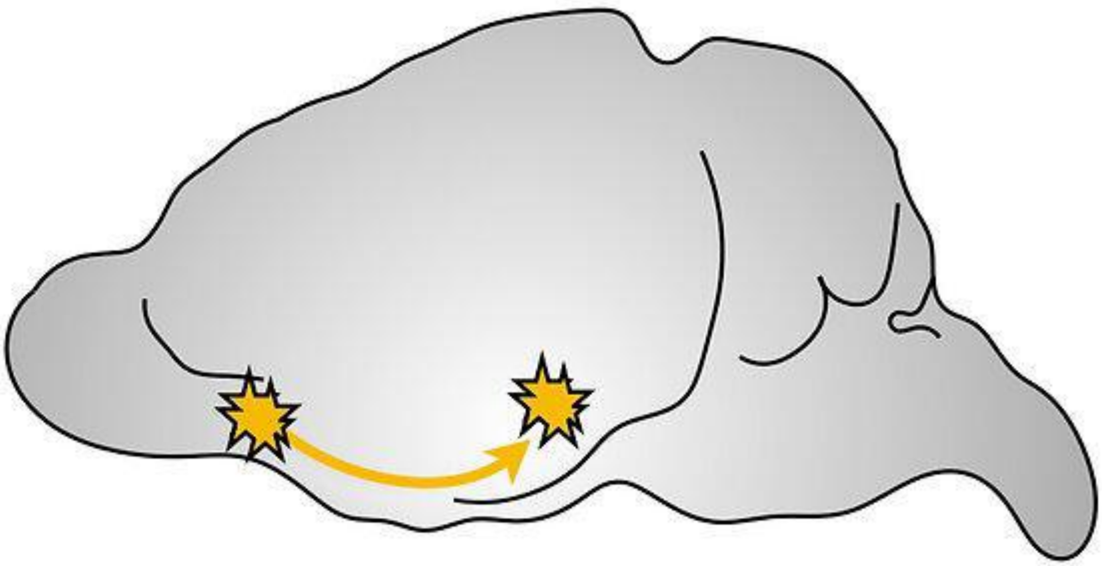
"They seem to represent a new substrate of information integration and association formation at the multicellular level," add Dityatev and Berretta.

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

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

Provided by University of Trento

Study sheds light on how the brain adapts hearing in different listening situations

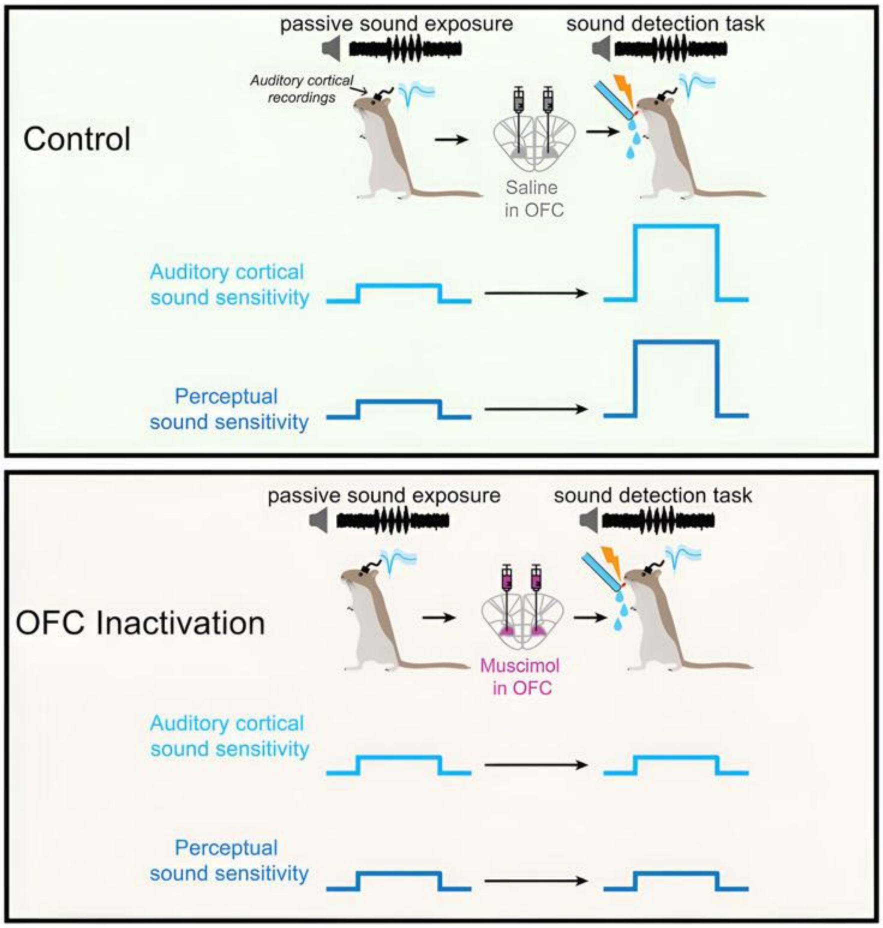


A diagram depicting the connection between the orbitofrontal cortex (OFC) and the auditory cortex. Credit: Melissa Caras© Provided by Medical Xpress

Have you ever noticed how you can suddenly hear your refrigerator humming in the background when you focus on it? Or how the sound of your name instantly catches your attention even in a noisy crowd?

The human brain is remarkably adept at adjusting what we hear based on context, like our current environment or priorities, but it's still unknown how exactly the brain helps us detect, filter and react to sounds.

Now, biologists at the University of Maryland are a step closer to solving that mystery. Using an animal model, the researchers found that the orbitofrontal cortex (OFC), a brain region associated with decision-making but not typically linked to hearing, plays a central role in helping the auditory cortex (a primary hearing center of the brain) adapt to changing contexts or situations. The team's findings were published in the journal *Current Biology* on July 11, 2024.



Graphical abstract. Credit: Current Biology (2024). DOI: 10.1016/j.cub.2024.06.036© Provided by Medical Xpress

"Our hearing doesn't just depend on the sounds around us. It also relies heavily on what we're doing and what's important to us at that moment," explained UMD Biology Assistant Professor Melissa Caras, the paper's senior author.

"Understanding the neural mechanisms responsible for these adjustments can also lead to a better understanding of and potential treatments for neurodevelopmental disorders like autism, dyslexia or schizophrenia—conditions where sensory regulation goes awry."

To closely examine the brain circuitry involved in the hearing process, the researchers turned to gerbils, small mammals whose basic hearing system is similar to that of humans. The animals were exposed to sound patterns in two different contexts. In one context, the animals listened to sounds passively without needing to do anything.

In the other, the animals had to perform a specific action in response to the sounds they heard. By recording and manipulating the brain activity of the animals, the team discovered that the OFC helped the animals switch between passive and active listening.

"In short, the OFC sends signals to the auditory cortex when it's time to pay closer attention to sounds," Caras said. "It's not certain whether the signals are sent directly or indirectly via an intermediary brain region, but we do know that activity in the OFC is essential to how the gerbils behaved in our experiments."

When the OFC was silenced, the animals' auditory cortex did not switch between passive and active listening, impairing their ability to pay attention to and react to a behaviorally relevant sound.

"In terms of a more human-oriented analogy, it would be as if I told you to suddenly pay attention to your refrigerator humming in the background," Caras explained. "If your OFC was silenced and unable to send a signal to your auditory cortex, you might have difficulty doing so because the ability to rapidly alter your sound perception would be impaired."

While this study was conducted in animals, Caras says the findings may have notable implications for human health and well-being. The ability to quickly shift attention to important sounds is essential for many day-to-day activities, including communicating with others and navigating busy or dangerous environments. "We're just beginning to understand how the brain fine tunes hearing sensitivity in response to sudden shifts in behavioral contexts. We plan to explore exactly how the OFC communicates with the auditory cortex and see whether it's possible to strengthen the connection and improve hearing ability," Caras said.

"This work is paving the way for researchers and health care professionals to develop better strategies for improving hearing in both healthy individuals and those with sensory impairments."

More information: Matheus Macedo-Lima et al, Orbitofrontal cortex modulates auditory cortical sensitivity and sound perception in Mongolian gerbils, *Current Biology* (2024). DOI: 10.1016/j.cub.2024.06.036

Provided by University of Maryland

Study discovers a 'brain thesaurus' that lets neurons derive meaning from spoken words

Using a novel technology for obtaining recordings from single neurons, a team of investigators at Massachusetts General Hospital, a founding member of the Mass General Brigham health care system, discovered a microscopic "thesaurus" that reflects how word meanings are represented by neurons in the human brain.

The research, which is published in *Nature*, opens the door to understanding how humans comprehend language and provides insights that could be used to help individuals with medical conditions that affect speech.

"Humans possess an exceptional ability to extract nuanced meaning through language—when we listen to speech, we can comprehend the meanings of up to tens of thousands of words and do so seamlessly across remarkably diverse concepts and themes," said senior author Ziv Williams, MD, a physician-investigator in the department of Neurosurgery at Massachusetts General Hospital and an associate professor of Neurosurgery at Harvard Medical School.

"Yet, how the human brain processes language at the basic computational level of individual neurons has remained a challenge to understand."

Williams and his colleagues set out to construct a detailed map of how neurons in the human brain represent word meanings—for example, how we represent the concept of animal when we hear the word cat and dog, and how we distinguish between the concept of a dog and a car.

"We also wanted to find how humans are able to process such diverse meanings during natural speech and through which we are able to rapidly comprehend the meanings of words across a wide array of sentences, stories, and narratives," Williams said.

To start addressing these questions, the scientists used a novel technology that allowed them to simultaneously record the activities of up to a hundred neurons from the brain while people listened to sentences (such as, "the child bent down to smell the rose") and short stories (for example, about the life and times of Elvis Presley).

Using this new technique, the investigators discovered how neurons in the brain map words to particular meanings and how they distinguish certain meanings from others.

"For example, we found that while certain neurons preferentially activated when people heard words such as 'ran' or 'jumped,' which reflect actions, other neurons preferentially activated when hearing words that have emotional connotations, such as 'happy' or 'sad,'" said Williams.

"Moreover, when looking at all of the neurons together, we could start building a detailed picture of how word meanings are represented in the brain."

To comprehend language, though, it is not enough to only understand the meaning of words, but also to accurately follow their meanings within sentences. For example, most people can rapidly tell the correct meaning of words such as "sun" and "son" or "see" and "sea" when used in a sentence, even though the words sound exactly the same.

"We found that certain neurons in the brain are able to reliably distinguish between such words, and they continuously anticipate the most likely meaning of the words based on the sentence contexts in which they are heard," said Williams.

Lastly, and perhaps most excitingly, the researchers found that, by recording a relatively small number of brain neurons, they could reliably predict the meanings of words as they were heard in real-time during speech. That is, based on the activities of the neurons, the team could determine the general ideas and concepts experienced by an individual as they were being comprehended during speech.

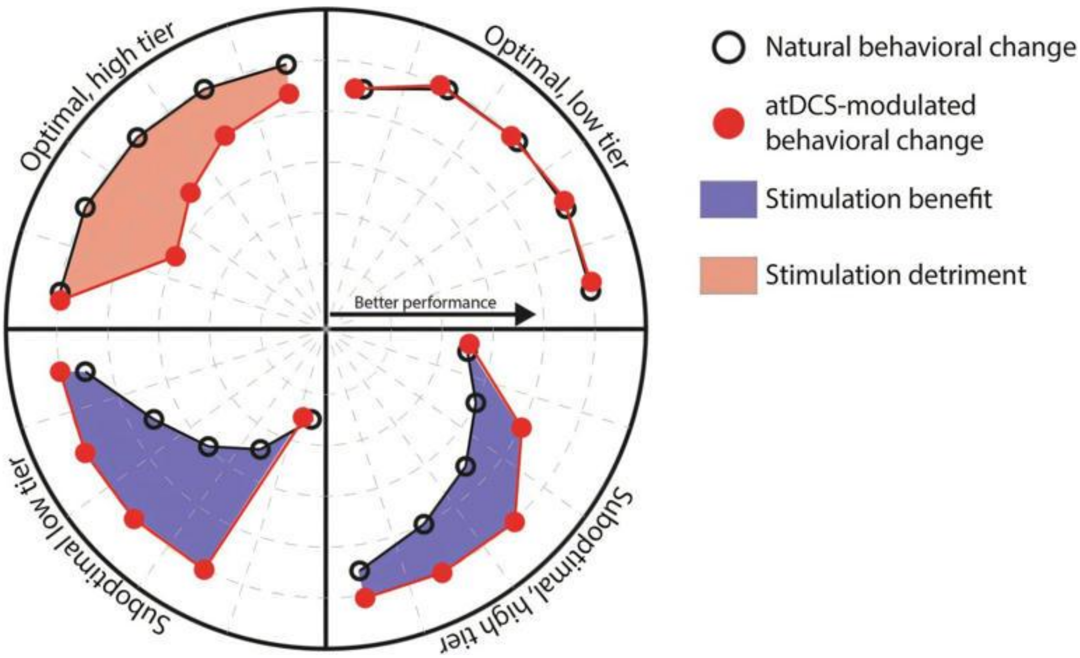
"By being able to decode word meaning from the activities of small numbers of brain cells, it may be possible to predict, with a certain degree of granularity, what someone is listening to or thinking," said Williams.

"It could also potentially allow us to develop brain-machine interfaces in the future that can enable individuals with conditions such as motor paralysis or stroke to communicate more effectively."

More information: Mohsen Jamali et al, Semantic encoding during language comprehension at single-cell resolution, *Nature* (2024). DOI: 10.1038/s41586-024-07643-2

Provided by Massachusetts General Hospital

Brain stimulation effectiveness tied to learning ability, not age



Main finding. Credit: npj Science of Learning (2024). DOI: 10.1038/s41539-024-00278-y

As we age, our cognitive and motor functions deteriorate, which in turn affects our independence and overall quality of life. Research efforts to ameliorate or even completely abolish this have given rise to technologies that show a lot of promise.

Among these is non-invasive brain stimulation: a term encompassing a set of techniques that can affect brain functions externally and noninvasively, without the need for surgery or implants. One such promising technique, in particular, is anodal transcranial direct current stimulation (atDCS), which uses a constant, low electrical current delivered via electrodes on the scalp to modulate neuronal activity.

However, studies exploring atDCS have produced inconsistent results, which has prompted researchers to explore why some people benefit from atDCS while others don't. The problem seems to lie in our understanding of factors that may influence responsiveness to brain stimulation, leading to responders and non-responders; among these, age has been suggested as one important factor.

Some studies suggest further factors such as baseline behavioral abilities and previous training might be important considerations, but an interplay of these factors with behavior has not been determined in detail, pointing to the need for refined predictive models of the effects of atDCS.

Now, scientists led by Friedhelm Hummel at EPFL have identified an important factor affecting an individual's responsiveness to atDCS. The team looked at how native learning abilities determine the effect of brain stimulation applied while learning a motor task.

Their work has been published in *npj Science of Learning*.

Their findings suggest that individuals with less efficient learning mechanisms benefit more from stimulation, while those with optimal learning strategies might experience negative effects.

The researchers recruited 40 participants: 20 middle-aged adults (50-65 years old) and 20 older adults (over 65). Each group was further divided into those receiving active atDCS and those receiving placebo stimulation.

Over ten days, participants practiced a finger-tapping task designed to study motor sequence learning at home while receiving atDCS. The task involved replicating a numerical sequence using a keypad, trying to be as fast and as accurate as possible.

The team then used a machine-learning model trained on a public dataset to classify participants as either "optimal" or "suboptimal" learners, based on their initial performance. This model aimed to predict who would benefit from atDCS, based on their ability to integrate information about the task efficiently early during training

The study found that suboptimal learners, who were seemingly less efficient at internalizing the task at the early stages of learning, experienced an accelerated accuracy improvement while performing the task when receiving atDCS. This effect was not limited to people of a certain age (e.g., older adults), with suboptimal learners being found among younger individuals as well.

In contrast, participants with optimal learning strategies, regardless of age, even showed a negative trend in performance when receiving atDCS. This difference suggests that brain stimulation is more beneficial for individuals who initially struggle with motor tasks. As such, atDCS seems to possess a restorative rather than an enhancing quality, with important implications for rehabilitation.

"By leveraging different methods in machine learning, we were able to untangle the influence of different factors on the individual effects of brain stimulation," says Pablo Maceira, the study's first author. "This will pave the way to maximize the effects of brain stimulation in individual subjects and patients."

The study implies that, in the long run, personalized brain stimulation protocols will be developed to maximize benefits based on an individual's specific needs, rather than a common trait such as age.

This approach could lead to more effective brain stimulation-based interventions, targeting specific mechanisms supporting learning, especially from the view of neurorehabilitation, for which the main basis is the re-learning of lost skills due to a brain lesion (e.g., after a stroke or a traumatic brain injury).

"In the future, clinicians could apply a more advanced version of our algorithm to determine whether a patient will benefit from a brain stimulation-based therapy, to enhance the effects of neurorehabilitation and personalize treatment," says Hummel.

More information: Pablo Maceira-Elvira et al, Native learning ability and not age determines the effects of brain stimulation, *npj Science of Learning* (2024). DOI: 10.1038/s41539-024-00278-y

Provided by Ecole Polytechnique Federale de Lausanne

Your Brain Is Not a Computer. It Is a Transducer

A new theory of how the brain works — neural transduction theory — might upend everything we know about consciousness and the universe itself.

By Robert Epstein
Aug 25, 2021 9:00 AMAug 25, 2021 1:24 PM

Let's start with my 95-year-old mom. Her memory is unreliable, but she's still lucid, churns out sarcasm like a pro, and plays a lightning-fast game of double solitaire. Today I finally quit after she won seven games in a row, and, yes, I was trying my best.

She also hears music continuously, and it's not the kind of music that drives us nuts when we can't get a tune out of our head. She mainly hears *original* music, and she will sometimes try to hum or sing what she's hearing. She says it's coming from "the neighbors downstairs," and it doesn't bother her, she says, because some of it isn't bad and because it helps her fall asleep. The fact that other people can't hear it doesn't bother her either. She simply smiles slyly and says, "Maybe you should get your hearing checked."

Am I concerned? Well, just a bit — not about the music but about its source. As I told my mom the other day, I would be more comfortable if the inconsiderate neighbors lived *upstairs*. She laughed and said, "I see what you're getting at, but don't worry. I'm *not* going to hell." Very determined, my mom. Was she planning to negotiate the issue with a hand of double solitaire?

Where is all this original music coming from? My mother has never composed music, and she insists she would be incapable of doing so "no matter how much you paid me." That's mom-speak for *case closed*.

In case you haven't noticed, we are surrounded by mysteries like this. Some, in my view, are highly suspect, such as demonic possession and communication with spirits. Others are undeniably real: dreams, daydreams, hallucinations, the *déjà vu* experience, and so on. My staff recently came up with a list of *58* such phenomena. You don't have to look far to find them.

Are we doomed to remain in the dark about these mysteries, or is there a way to peel back the veil? What if spirits, dreams, and my mom's music could all be accounted for by a relatively simple idea about how the brain works — an idea that might even be testable?

The idea, which is quite simple on its face, is that the brain is a bidirectional transducer.

Transduction Is All Around Us

A few inches to the left of the laptop computer on which I am now typing stands an imposing Sennheiser microphone that I use mainly when someone is interviewing me for a radio or TV show. A thick black cable protrudes from the back of the microphone and snakes its way to a boxy analogue-to-digital converter, which links to my computer via a bright red USB cable.

My computer links wirelessly to a router in the next room, and the router connects to AT&T, my internet service provider, through a telephone cable that runs from the router to a wall socket. That cable leads to dozens of other transition points through which crude representations of my voice pass before some semblance of it is finally heard by a talk-show host in, say, London.

If I'm speaking to a host of a BBC radio program, representations of his or her voice are also traveling in the other direction from his or her microphone through dozens of transition points until they finally activate a tiny speaker in my ear bud, through which I hear a semblance of his or her voice. If we're also using video to communicate, cameras are sending images to screens, again through many transition points, and again in both directions.

Representations of these images and sounds might be passing not only through multiple transition points but also through thousands of miles of copper or fiber optic cables, or are perhaps being transmitted to satellites hundreds of miles above the earth and then re-transmitted to receivers on the ground. Long ago, pathways like this could accommodate only one conversation at a time, with communications running in only one direction at a time, but now such pathways are bidirectional and are often shared simultaneously by thousands of different conversations.

Remarkably, when everything is working smoothly, my conversation with the London host is as seamless as it would be if we were in the same room. Even though I'm 5,500 miles away in San Diego, I can't detect any time gaps between my ramblings and the host's reply. Those gaps exist, but they're so short that neither I nor the host can perceive them.

What's happening here? Is my voice actually traveling 5,500 miles? Definitely not. If you were the proprietor of a 19th century mansion, you might have been able to shout into a speaking tube that snaked its way through your home and carried your voice all the way to the servants' quarters. In that case, the sound of your voice was literally carried to its destination by the air in the tube.

But when I speak into my microphone, the pattern of sound waves produced by my voice — a distinctive, non-random pattern of air pressure waves — is being *converted* by the microphone into a similar pattern of electrical activity. The better the microphone, the more accurately it duplicates the original pattern, and the more I sound like me at the other end.

That conversion process — the shifting of a meaningful, non-random pattern of activity — from one medium (say, the air in front of the microphone) to another medium (say, the wire at the back of a microphone) is called *transduction*.

And transduction is all around us, even in organic processes. Our bodies are completely encased by transducers. Our sense organs — eyes, ears, nose, tongue, and skin —transduce distinctive properties of electromagnetic radiation, air pressure waves, airborne chemicals, liquid-borne chemicals, textures, pressure, and temperature into distinctive patterns of electrical and chemical activity in the brain. Organic compounds can even be used these days to create new kinds of transducers, such as OECTs: **organic electrochemical transistors**.

Evolution didn't just create millions of new species of organisms, it also created millions of new types of transducers, and engineers are now using both organic and inorganic materials to create thousands more.

To repeat (because this is important): Transduction is all around us — forms of transduction that have evolved over eons and new forms of transduction that humans are inventing right now.

The Ultimate Transducer

What if evolution, at some point, produced a special kind of transducer that could shift signals from the physical world as we know it to a very different kind of world?

Nearly all religions teach that immaterial realms exist that transcend the reality we know. For Christians and Muslims, those realms are Heaven and Hell. One of the simplest and clearest statements of such a concept comes from ancient Greek mythology: As long as the deceased had the required toll in hand — well, actually in mouth — he or she would be transported by the ferryman Charon across the river Styx to Hades, the land of the dead — quite literally, to the *Other Side*. (I'll call it the OS from this point on.) Unfortunately, not everyone was eligible to make the crossing. If no one thought to bury you or to put that coin in your mouth, you were doomed to roam *this* side of the river as a ghost.

The idea of a realm transcending the one we experience directly has taken on many forms over the centuries. George Griffith, England's most prominent and prolific science fiction writer of the late 1800s, published a prescient novel about this realm in 1906: ***The Mummy and Miss Nitocris: A Phantasy of the Fourth Dimension***. The book's protagonist, professor Franklin Marmion, is a distinguished mathematician and physicist who anticipates discoveries and concepts that real quantum physicists would eventually propose decades later. Over the course of the story, Marmion not only reluctantly accepts the fact that a higher dimension must exist, he also acquires the power to shift his body there, learning, among other counterintuitive things, that multiple objects can occupy the same space at the same time.

Griffith might have been aware of a contemporary of his, William James, a prominent Harvard philosopher and also arguably America's first psychologist. In 1898, James published a short book entitled ***Human Immortality: Two Supposed Objections to the Doctrine***, in which he praised his contemporaries for boldly using scientific methods to investigate "providential leadings [sic] in answer to prayer, instantaneous healings, premonitions, apparitions at time of death, clairvoyant visions or impressions, and the whole range of mediumistic capacities."

James asserted that a universe-wide consciousness beamed human consciousness into our brains "as so many finite rays," just as the sun beams rays of light onto our planet. Our brains, being limited in their capabilities, he said, generally filter and suppress real consciousness, while sometimes allowing 'glows of feeling, glimpses of insight, and streams of knowledge' to shine through. He called this idea 'transmission-theory.'

Ideas like James's have been around for thousands of years. In his 2006 book, *Life After Death: The Burden of Proof*, alternative medicine guru Deepak Chopra says that ancient Hindu texts teach that the material world we know is nothing but a projection from the universal consciousness that fills all space. From this perspective, death is not an end; it is a merging of a relatively pathetic human consciousness with that of the dazzling universal one. To add gravitas to this idea, Chopra does what many recent authors have done: he suggests that modern formulations of quantum physics are consistent with his belief in a universal consciousness.

The connection between physics and modern theories of mind and consciousness is **tenuous at best**, but modern physicists do take the idea of parallel universes seriously. They debate the details, but they can hardly ignore the fact that the mathematics of **at least three** of the grand theories at the core of modern physics — inflation theory, quantum theory, and string theory — predict the existence of alternate universes. Some physicists even believe that signals can leak between the universes and that the existence of parallel universes **can be confirmed** through measurements or experiments. In a recent essay, physicist **A. A. Antonov** argues that our inability to detect the vast amount of dark energy that almost certainly exists in our own universe is evidence of the existence of parallel universes, six of which, he speculates, are directly adjacent to our own.

Again, setting the details aside, physicists agree that the three-dimensional space we experience is simply not the whole picture. As theoretical physicist Lee Smolin put it recently, "**Space is dead**."

Evidence for Transduction?

Hard evidence that supports a neural transduction theory is lacking at the moment, but we are surrounded by odd phenomena that are at least consistent with such a theory. And, no, I'm not talking about the claims that best-selling authors have made over the decades about proof that telepathy, out-of-body experiences, and communication with the dead are real. No such proof exists, in my view, but other well documented phenomena are difficult to brush aside.

When I was a graduate student at Harvard, I noticed a stranger roaming the hallway near my office and offered to assist her. Doris, it turns out, had heard voices for years, and she was hoping she could find someone in the psychology building — William James Hall — to help her eliminate them because they "caused trouble." I didn't have the heart to tell her that Harvard, at the time, had no clinical psychology program and that I was doing behavioral research with pigeons. If her voices had sent her there, they were troublemakers indeed.

When internal perception goes awry, people can be overwhelmed by hallucinations, visions, or distortions of reality so extreme they have to be hospitalized, and Doris had been hospitalized at times.

But is Doris that different from the rest of us? After all, even the healthiest among us hallucinate several times each night — we call it dreaming. And we all have at least two highly disorienting experiences each day called "hypnogogic states" — those eerie, sometimes creative interludes between sleeping and waking.

I have sometimes dreamt intricate full-length movies that seemed as good as any Hollywood film. Alas, most of the time, no matter how hard I try, I can't seem to hold on to even a shred of a dream during the few seconds when I'm staggering from my bed to the bathroom.

Where does all this content come from, and why do we have so little control over it?

In recent years, researchers have explored what they have clumsily labeled "paradoxical lucidity," or, even worse, "*terminal* lucidity." These labels refer to what some of us know as "the last hurrah" — the burst of mental clarity that sometimes occurs shortly before people die, even people for whom such clarity should be impossible.

For more than two centuries, medical journals have published credible reports of highly impaired, uncommunicative people who suddenly became lucid for a few minutes before they died. There are documented cases in which people with dementia, advanced Alzheimer's, schizophrenia, and even severe brain damage —– people who have not been able to speak or to recognize their closest relatives for years — suddenly recognized their loved ones and spoke normally.

A 2020 study summarizing the observations of 124 caregivers of dementia patients, concluded that in "more than 80 percent of these cases, complete remission with return of memory, orientation, and responsive verbal ability was reported by observers of the lucid episode" and that '"[the] majority of patients died within hours to days after the episode." The periods of lucidity typically lasted 30 to 60 minutes.

Some of the historical reports of lucid episodes are truly extraordinary.

Here is one of many cases **reported by the German biologist Michael Nahm** and his colleagues in 2012:

In a case published in 1822, a boy at the age of 6 had fallen on a nail that penetrated his forehead. He slowly developed increasing headaches and mental disturbances. At the age of 17, he was in constant pain, extremely melancholic, and starting to lose his memory. He fantasized, blinked continuously, and looked for hours at particular objects.... He remained in the hospital in this state for 18 days. On the morning of the 19th day, he suddenly left his bed and appeared very bright, claiming he was free of all pain and feelings of sickness.... A quarter of an hour after the attending physician left him, he fell unconscious and died within a few minutes. The front part of his brain contained two pus-filled tissue bags the size of a hen's egg (Pfeufer, 1822)....

And another:

Haig (2007) reported the case of a young man dying of lung cancer that had spread to his brain. Toward the end of his life, a brain scan showed little brain tissue left, the metastasized tumors having not simply pushed aside normal brain tissue but actually destroyed and replaced it. In the days before his death, he lost all ability to speak or move. According to a nurse and his wife, however, an hour before he died, he woke up and said good-bye to his family, speaking with them for about five minutes before losing consciousness again and dying.

If the brain is a self-contained information processor, how can we explain the sudden return of lucidity when the brain is severely damaged? For that matter, think about the variability that occurs in your own lucidity over the course of 24 hours, during which you are, at various times, completely unconscious, partially conscious, or fully conscious. If you add drugs and alcohol to the picture, the variability is even greater, and it can be quite bizarre.

The variability problem is addressed in an **intriguing paper** published by Jorge Palop and his colleagues in *Nature* in 2006, who note that patients suffering from a variety of neurodegenerative disorders often fluctuate over the course of a single day between states of extreme confusion and relatively normal mental states. Such radical changes, they note, "cannot be caused by sudden loss or gain of nerve cells." They speculate about changes in neural networks, but that doesn't solve the problem.

What if the variability is not caused by changes in processing power in the brain but rather by transduction effects? By changes occurring not in our local universe but in the OS? Or by minor changes occurring at the point of connection? Or by changes occurring in brain structures that are essential to signal transfers?

I've also been intrigued by what appear to be credible reports about visual experiences that some congenitally-blind people have had when they were near death. Experiences of this sort were first summarized in a **1997 paper** by Kenneth Ring and Sharon Cooper, later expanded into a book called *Mindsight* (1999). The paper and book describe the experiences of 14 people who were blind from birth and who had near-death experiences (NDEs), some of which included content that appeared to be visual in nature. Soon after Vicki U. was in a near-fatal car accident at age 22, she remembered "seeing" a male physician and a woman from above in the emergency room, and she "saw" them working on a body. Said Vicki:

I knew it was me.... I was quite tall and thin at that point. And I recognized at first that it was a body, but I didn't even know that it was mine initially. Then I perceived that I was up on the ceiling, and I thought, "Well, that's kind of weird. What am I doing up here?" I thought, "Well, this must be me. Am I dead?"

Vicki had never had a visual experience before her NDE, and, according to the researchers, did not even "understand the nature of light." While near death, she also claimed to have been flooded with information about math and science. Said Vicki:

I all of a sudden understood intuitively almost [all] things about calculus, and about the way planets were made. And I don't know anything about that.... I felt there was nothing I didn't know.

Several aspects of Vicki's recollections are intriguing, but the most interesting to me are the visual experiences. How can someone who has never had such an experience "No light, no shadows, no nothing, ever," according to Vicki — suddenly have rich and detailed experiences of this sort? Ring and Cooper found others like Vicki – congenitally blind people who not only had visual experiences when near death but whose NDEs were remarkably similar to some common NDEs of sighted people.

Just recently, an Australian woman **made the news** worldwide when, post surgery, she woke up with an Irish accent. Her strong Australian accent was completely gone. Called 'the foreign accent syndrome', this sudden switch in accents is rare but real. The shift doesn't make sense given the framework of reasoning we usually apply to the world, but what if it's a transduction error?

And why can't we remember pain? We can remember facts and figures and images, and we can even get choked up remembering strong emotions we've felt in the past — but *we can't remember pain*. Are sensations of pain getting filtered out by transduction pathways? Could that be why our dreams are pain free? That begs a question that is both eerie and obvious: Is the OS a kind of pain-free Heaven?

And have you ever met a stranger who made you feel, almost immediately, that you had known him or her your entire life? And sometimes this stranger has the same feeling about *you*. It's a strong feeling, almost overwhelming. We can try to explain such feelings with speculations about how a voice or physical characteristics might remind us of someone from our past, but there is another possibility — that in some sense *you had actually known this person your whole life*. If the brain is a bidirectional transducer, that is not a strange idea at all.

In fact, when viewed through the lens of transduction theory, *none* of these odd phenomena — dreams, hallucinations, lucidity that comes and goes, blind vision, and so on — looks mysterious.

And All That Jazz

This brings me, reluctantly, to the recent rise of "postmaterialist" science, or at least postmaterialist psychology. The latter is marked by — or perhaps blemished by — the founding of the journal *Spirituality in Clinical Practice* by the American Psychological

Association (APA) in 2014 and the founding of the Association for the Advancement of Postmaterialistic Sciences in 2017. (Disclosure: I have been a full member of the APA since 1983.)

Postmaterialism is all about controlled experiments that have supposedly proved, or at least supported, claims that mediums can communicate with the dead, that ghosts will happily comply when we ask them to climb into little boxes in a laboratory, that people can send their thoughts to strangers in another room telepathically, and that future events can somehow travel backward in time to impact people's current behavior.

I am *so* tempted here to start naming names and tearing down reputations, but my musical mom raised me better than that. I will say this: One of the early papers published in that new APA journal — a paper that was accepted without peer review — demonstrated thinking so shoddy it startled me.

Fortunately, I don't *need* to tear apart shoddy thinking or flawed experiments to advocate for transduction theory. In fact, if this theory proves to be valid, every fantasy of the postmaterialists will be fulfilled — every fantasy except one, that is, and that is *the postmaterialist claim itself*. That's because parallel universes are not wispy, physics-free spiritual entities; according to many mainstream physicists, they are just non-obvious companions of the material universe in which we happen to live.

A Better Brain Theory

Let's set aside both the mundane and the exotic reasons we should take transduction theory seriously and get to the heart of the matter: The main reason we should give serious thought to such a theory has nothing to do with ghosts. It has to do with the sorry state of brain science and its reliance on the computer metaphor. One of my research assistants recently calculated that Beethoven's thirty-two piano sonatas contain a total of 307,756 notes, and that doesn't take into account the hundreds of sections marked with repeat symbols. Beethoven's scores also include more than 100,000 symbols that guide the pianist's hands and feet: time signatures, pedal notations, accent marks, slur and trill marks, key signatures, rests, clefs, dynamic notations, tempo marks, and so on.

Why am I telling you about Beethoven? Because piano virtuoso and conductor Daniel Barenboim memorized *all thirty-two of Beethoven's sonatas by the time he was 17*, and he has since memorized hundreds of other major piano works, as well as dozens of entire symphony scores — *tens of millions* of notes and symbols.

Do you think all this content is somehow *stored* in Barenboim's **ever-changing, ever-shrinking, ever-decaying brain**? Sorry, but if you study his brain for a hundred years, you will never find a single note, a single musical score, a single instruction for how to move his fingers — not even a "representation" of any of those things. The brain is simply *not* a storage device. It is an extraordinary entity for sure, but not because it stores or processes information. (See my *Aeon* essay, "**The Empty Brain**," for more of my thinking on this issue, and for a truly great thrill, watch Barenboim play the third movement from Beethoven's 14th piano sonata **here**.)

Over the centuries — completely baffled by where human intelligence comes from — people have used one metaphor after another to 'explain' our extraordinary abilities, beginning, of course, with the divine metaphor millennia ago and progressing – and I use that word hesitatingly — to the current information-processing metaphor. I am proposing now that we abandon the metaphors and begin to consider substantive ideas we can test.

To be clear: I am *not* offering transduction theory as yet another metaphor. I am suggesting that the brain is truly a bidirectional transducer and that, over time, we will find empirical support for this theory.

Recall that Einstein's Special Theory of Relativity, published in 1905, and then his General Theory of Relativity, published in 1915, received no direct and convincing empirical support for years — first regarding predictions his equations made about the perihelion precession of Mercury's orbit, then about the bending of light around the sun (observed by Sir Arthur Eddington in 1919), and then about the gravitational redshift of light. It took a full century before his predictions about gravity waves were confirmed.

If we can cast some aspects of transduction theory into formal, predictive terms (I'm working on that now and am looking for collaborators), we might be able to make specific predictions about transduction — about subtle variations in reaction times, for example, or about how transduction errors might help us explain schizophrenia. We might also be able to predict quantitative aspects of dreams, daydreams, hallucinations, and more.

Ignore It at Your Peril

If transduction theory has merit, let's think about what happens if we ignore it. If we transported a 17th century scientist to the present day and showed him or her how well we can converse with someone using a cell phone, he or she would almost certainly want to look inside the phone. The remote voice must be *in* the phone, after all. To put this another way, a Renaissance scientist would naively view the phone as a self-contained processing unit, much as today's brain scientists naively view the brain.

But that scientist will never find the remote voice inside the phone, because it is not there to be found.

If we explain to the scientist that the phone is a transducer, however, he or she will now examine the phone in a different way, searching for evidence of transduction, which he or she — aided by appropriate instruments and knowledge — will eventually find.

And here is the problem: If you *never* teach that scientist about transduction, he or she might *never* unravel the mysteries of that phone.

This brings me to the claustrum, a small structure just below the cerebral cortex that is **poorly understood**, although **recent research** is beginning to shed some light. Many areas of the brain connect to the claustrum, but what does it do? If the claustrum turns out to be the place where signals are transduced by the brain, *you will probably never discover this remarkable fact if transduction is not on your list of possibilities.* (If you're a history buff, you might also be aware of another small brain structure — the pineal gland — that could conceivably be a transduction site. In his first book, *Treatise of man*, written in the early 1600s, French philosopher René Descartes identified this gland as the seat of the soul. Remarkably, in the late 1900s, **scientists discovered** that tissue in the pineal gland responds to electromagnetic radiation.)

If modern brain scientists begin to look for evidence that the brain is a transducer, they might find it directly through a new understanding of neural pathways, structures, electro-chemical activity, or brain waves. Or they might find such evidence indirectly by simulating aspects of brain function that appear to be capable of transducing signals. They might even be able to create devices that send signals to a parallel universe, or, of greater interest, that *receive* signals from that universe. Comparative studies of animal brains, which could conceivably have limited connections to the OS, might help move the research along.

Efficient and clear transduction might also prove the key to understanding the emergence of human language and consciousness; here is a possible explanation for what might have been the relatively sudden appearance of such abilities in humans (see Julian Jaynes's 1976 book, *The Origin of Consciousness in the Breakdown of the Bicameral Mind*). Neural transduction might also prove to be the mechanism underlying Carl Jung's concept of the "collective unconscious." Even Noam Chomsky's theory of universal grammar could get a boost from transduction theory; it would hardly be surprising that most or all human languages share certain grammatical rules if languages are all constrained by signals emanating from a common source. And then there's that 'flow' state my friend Mihaly Csikszentmihalyi taught everyone about. When I'm in a hyper-creative mode – now, for example, as I'm writing – I have almost no awareness of this world or of the passage of time. Is the OS the source of our creativity?

It might take decades for us to see significant advances in transduction research, but with vast resources already devoted to the brain sciences, we could conceivably move much faster. And if you're worried that transduction theory is just another one of those inherently untestable theories — like string theory or theories about parallel universes — think again. With neural transduction theory, we have an enormous advantage: *The transduction device is available for immediate in-depth study*.

Implications and Final Notes

Will transduction theory finally clear up the old consciousness problem? That I doubt, because I don't think there *is* a consciousness problem. Consciousness is just the experience we have when we're observing ourselves or the world. It seems grand simply because we're part of the system we're observing. It's a classic example of how difficult it can be to study a system of which one is an integral part; think of this problem as a kind of Gödel's theorem of the behavioral sciences. (For my whole spiel on this issue, see my 2017 essay, "**Decapitating Consciousness**.")

If transduction theory proves to be correct, our understanding of the universe and of our place in it will change profoundly. We might not only be able to make sense of dozens of odd aspects of human experience, we might also begin to unravel some of the greatest mysteries in the universe: where our universe came from, what else and who else is out there — even whether there is, in some sense, a God.

If you are as skeptical about flimsy theories as I am, by now you might be thinking: Has Epstein lost his mind (and, if so, where did it go)? Let me assure you that I am as hard-headed as ever. I won't believe in ghosts until Casper himself materializes in front of an audience and pushes me off the stage. But I am also acutely aware of how little we actually know, both about ourselves and our universe. If one simple idea — brain as transducer — might stimulate new kinds of research and might also bring order to what seem to be scores of unrelated, bizarre, and highly persistent human beliefs, I'm all for it.

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Consciousness Beyond Neural Fields: Expanding the Possibilities of What Has Not Yet Happened

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Abstract

In the field theories in physics, any particular region of the presumed space-time continuum and all interactions between elementary objects therein can be objectively measured and/or accounted for mathematically. Since this does not apply to any of the field theories, or any other neural theory, of consciousness, their explanatory power is limited. As discussed in detail herein, the matter is complicated further by the facts than any scientifically operational definition of consciousness is inevitably partial, and that the phenomenon has no spatial dimensionality. Under the light of insights from research on meditation and expanded consciousness, chronic pain syndrome, healthy aging, and eudaimonic well-being, we may conceive consciousness as a source of potential energy that has no clearly defined spatial dimensionality, but can produce significant changes in others and in the world, observable in terms of changes in time. It is argued that consciousness may have evolved to enable the human species to generate such changes in order to cope with unprecedented and/or unpredictable adversity. Such coping could, ultimately, include the conscious planning of our own extinction when survival on the planet is no longer an acceptable option.

Keywords: field theory, physics, consciousness, evolution, deep meditation, aging and wellbeing people, *eudaimonia*

Introduction

In field theories of consciousness (e.g., Köhler, 1940; Cacha and Poznanski, 2014 among others), the latter is conceived in terms of a field in the sense in which it is used in quantum or particle physics, where the notion of "field" applies to all fundamental forces and relationships between elementary particles within a unifying theoretical framework where the forces lead to energy fields that occupy space-time and mediate interactions between elementary particles. In field theories of consciousness the latter is, similarly, seen as having duration and extension in space. In field theories in physics, however, each point of a particular region of the presumed space-time continuum, as well as all interactions between elementary objects, are objectively measurable and accounted for mathematically. This cannot be claimed by any current theory of consciousness, including the field theories (e.g., Köhler, 1940; Lashley et al., 1951; Fingelkurts and Fingelkurts, 2002; John, 2002; McFadden, 2002; Cacha and

Poznanski, 2014). These will not be reviewed in detail again here, as an excellent review has been provided earlier by Pockett (2013) earlier. Reasons why Libet's Mind Field Theory of consciousness, carved out in his book *Mind Time* (2004), may be discussed outside rather than within the realm of the other field theories are clarified herein. Neural field theories of consciousness, whether they relate to representational fields, where *Gestalten* or *qualia* are seen as reflecting the very nature of consciousness, occupying a presumed spatio-temporal brain field generating electrical brain states (Köhler, 1940), or to the functionally specific spatio-temporal structure of an electromagnetic field in the brain (Lashley et al., 1951; Fingelkurts and Fingelkurts, 2002; John, 2002; McFadden, 2002), all account for specific aspects of brain-behavior function while humans are in a conscious or non-conscious state. Yet, consciousness is a far more complex product of brain evolution, both at the phylogenic (Cabanac et al., 2009) and at the ontogenetic (Jaynes, 1990; Feinberg and Mallatt, 2013) scales, that reaches well beyond brain-behavior function (e.g., Pockett, 2004). Since the theory of evolution, the problem of the origin of mind or, more specifically, the origin of consciousness has been posed. Where and how in evolution has it begun to emerge, and how can it be measured. How can we derive mindfulness out of mere biophysical matter? If we want to define consciousness adequately, it would need to be in terms of the capability of the human Self to know and analyze its own condition and existence in space and time, and to project this knowledge into a future that has not yet happened. Why it may not be possible to render the whole complexity of the phenomenon of consciousness scientifically operational is discussed further in the following chapters. Ontological links between mind, time, and the Self as a window to understanding a specific aspect of human consciousness, the ability to project one's own existence into the future, are brought forward. Finally, the question whether we need neural field theories of consciousness as an explanation of the latter at all is justified under the light of clear argumentation. It is concluded that investigating functional links between eudaimonic well-being and consciousness could give us answers more important to the future of humankind.

Limitations to a Scientifically Operational Definition of Consciousness

None of the field theories of consciousness has succeeded in providing a definition that would be both scientifically operational and, at the same time, capture the complex nature of this phenomenon. This was already pointed out some time ago by Block (2007) as a clear limitation to not only field theories, but any theory of consciousness. He argued for an "abstract solution" to the "problem of consciousness" given that phenomenal consciousness by far exceeds perception, cognitive accessibility and performance, or any of their directly measurable brain correlates. What others have referred to as the "hard problem of consciousness" (e.g., Chalmers, 1996; Searle, 1998) relates to the difficulty of finding brain measures of a highly complex phenomenon, the conscious *Self*, experienced in terms of *I do*, *I think*, *I feel, I was, am, and will be*, independently of any particular conscious perception, memory, decision, or action (behavior). If a representational or neural field of consciousness occupying a presumed space-time continuum inside the brain, or outside the brain, as suggested by Sheldrake

(2013) and others, exists, it would have to be independent of the neural activities underlying any particular perceptual or cognitive process operating at the same time. While a specific conscious perception or conscious memory recall, can be measurably correlated with specific brain activities (e.g., Nani et al., 2019), interpreted adequately as the neural correlates of the particular conscious behavior being measured, it is not a neural correlate of consciousness. The contents of phenomenal experience are associated with neural activities in multiple networks (Rees et al., 2002) of the temporal-parietal-occipital brain areas, but this does not account for how and why, or through which mechanisms, our brain has evolved consciousness, while most other mammal brains have not, or at least not to the same extent. To get around this problem, the concept of a “conscious brain state,” with an abstract and scientifically operational definition of consciousness in terms of a “continuous process with limited duration” was introduced (Tononi and Edelman, 1998, and subsequently within a larger theoretical framework of consciousness, Edelman, 2003) based on a definition proposed earlier (von der Malsburg, 1997). Such a parsimonious definition of consciousness may allow looking for invariant properties of a brain state during conscious wakefulness and its equivalents. LaBerge et al. (1986) and LaBerge (1990) argued that states of lucid dreaming, for example, are equivalent to wakeful conscious states. The invariant properties of what John called “the conscious ground state,” which in his theory corresponds to a specific EEG wave pattern that is observed when patients recover from deep anesthesia, could then be told apart from the subjective phenomenal contents of any particular conscious experience as reflected in a particular overt behavior. In other words, the conscious brain state would have universal properties that can be consistently identified and measured whether we are consciously daydreaming (Singer, 1975; Carver and Humphries, 1981), engaged in abstract analytic thinking (Gilead et al., 2014), in a state of lucid dreaming (LaBerge, 1990), or whether we consciously perceive and remember objects, as in conscious three-dimensional perception and selective memory recall (Nani et al., 2019). Invariant or universal properties of a generic conscious brain state were, however, never found elsewhere than in brain patterns measured after recovery from deep anesthesia (John, 2002), which is, yet again, only a particular conscious state to which consciousness is not reducible. Fifteen years ago, the nuclear physicist Jean Durup and myself (Dresp-Langley and Durup, 2009) suggested a biophysical brain code independent of particular cognitive processes operating while we are conscious (perception, spatial awareness, conscious motor planning and execution etc.), but providing a generic neural mechanism that would trigger, maintain, and terminate an individual conscious state in similar ways in which electronic bar codes may activate, maintain, and disable the electronic locks of a safe. The functional assumptions underlying this somewhat wild concept were inspired by earlier work on an arbitrary, and possibly genetically prewired, selection of dedicated neural circuitry for consciousness (Helekar, 1999), temporal coincidence coding in the brain (e.g., Ainsworth et al., 2012), and adaptive resonance theory (Grossberg, 1999, 2000). Our idea then was to carve out a computational hypothesis for conscious in terms of a purely temporal (time bin) resonance of memory signals in long-range neural circuits well beyond functionally identified sensory areas. Such circuitry would first be arbitrarily selected and short-term potentiated by Hebbian synaptic learning, then subsequently consolidated during ontogenesis, long-term potentiated and dedicated to the generation of temporal signatures (firing patterns) of conscious states. Since consciousness is fully operational in the absence of spatially defined stimulus input from the outside world (when we have our eyes closed and daydream, for example, or in lucid dreaming), we daringly proposed that the temporal signatures of consciousness generated in dedicated neural circuits could become progressively de-correlated from spatial signals during ontogenesis. This hypothesis negates the concept of a spatially defined activity field within the brain as a potential correlate of consciousness, and it makes sense under the light of the fact that the phenomenon itself has no measurable spatial dimensionality. Brain activity patterns are representations, as adequately and parsimoniously defined earlier by Churchland (2002), in terms of patterns of activity across groups of neurons which carry information. Interpretations of such patterns in terms of functionally specific correlates (correlate = co-occurring with) of consciousness under specific conditions of testing (for a recent review, see for example, Koch et al., 2016) all carefully avoid the term causality, as correlation does not necessarily imply causality. Thus, when it comes to an *explanation* of consciousness, we are still found wanting, consistently faced with the same old problem, over and over again. It has up to now not been possible to confirm that specific brain activity patterns, or synchronization thereof, recorded during a specific conscious experience, explains consciousness, or even leads to an understanding of the phenomenon. This is so, because we do not know beyond reasonable doubt whether the brain activity patterns demonstrated in any of the relevant studies in the field are neural signatures of consciousness, or nothing more (or less) than the traces of different levels of integrated brain activity (see also the review by Pockett, 2013), representing ongoing sensations, memories, or mental images during conscious experience.

Absence of a Spatial Dimensionality of Consciousness

Consciousness has no observable spatial dimensionality (e.g., Libet, 2004; Buzsáki, 2007; Marchetti, 2014). It corresponds to a specific state of being in time independent of spatial location. It is a phenomenon that can be observed and accounted for scientifically across changes with time in ontogenetic development. The ability of human beings to both consciously relive past events and conceive future events (Callender, 2010; Carroll, 2010) entails an active process of construction of consciousness in time that underpins many other important aspects of conscious human life. During early childhood, the brain learns about the temporal order of the physical world, well before we become phenomenally conscious of a *Self* and its immediate or distant environments (Piaget, 1967). The temporal rhythms or order of stimuli is the first way through which humans acquire knowledge of physical reality, structure, and continuity, as illustrated by results from experiments where the responses of newborns exposed to speech stream inputs have been systematically quantified (Bulf et al., 2011). Human awareness of temporality and the projection of the *Self* and its most abstract concepts and reasoning toward a future that has not yet happened occurred relatively late in evolution as a mental capacity allowing to push the technological and cultural development of our species further and further. It develops ontogenetically over the first years of an individual lifespan (Piaget, 1967; Jaynes, 1990; Edelman, 1993). The idea of ontological identity link between consciousness and awareness of temporality harks back to Hume (1740), Hegel (1807), and Heidegger (1927) concepts of *Sein* (Being) and *Zeit* (Time), where consciousness is hardly more than a succession of psychological moments where we realize that we exist in, and are part of, moments in time. This places all other perceptual or sensorial processes which may characterize any particular phenomenal experience at a different level of analysis. The idea of a fundamental identity link between awareness of Self (*das Ich*) and awareness of what Heidegger termed *Ursprüngliche Zeit* (original time) implies that human consciousness may have progressively evolved from the primitive ability to be aware of, to remember, and to predict temporal order and change in nature found in other species such as rodents (e.g., Fouquet et al., 2010). The limits of this capacity are directly determined by brain capacity and extent of interaction between the brain and the world. The activity of individual neurons in the brain only has a small quantifiable relationship to sensory representations and motor outputs. The most recent evidence (Ainsworth et al., 2012) confirms that coactivation of a few 10s–100s of neurons can code sensory inputs and behavioral task performance within clear psychophysical limits. However, in a sea of sensory inputs with memory representations linked to complex motor output, the temporal activity of neurons has to be functionally organized independent of spatial codes relative to sensory data and representations. In the brain, this could be made possible either through spike rates (rate coding), or the selective reinforcement of spike coincidences active neurons and networks (temporal coding). Both have computational advantages and are not mutually exclusive. There is recent evidence (Ainsworth et al., 2012) for a bias in neuronal circuits toward temporal coding. Just as the temporal signal sequence or activity pattern of any single coding cell is determined by its firing activity across a certain length of time, the temporal signature of a conscious state is also linked to duration, with variations in the limited dynamic range of a few hundreds of milliseconds. Most perceptual and cognitive contents are processed implicitly by the brain (i.e., non-consciously) and truly conscious states seem to be reflected by short oscillatory activity periods of not more than a few hundreds of milliseconds each (e.g., Buzsáki, 2007; del Cul et al., 2009; Nyberg et al., 2010). The clockworks of consciousness have thus been conceived in terms of rapid temporal successions of microscopic brain states Edelman, 2003). Spike time-based models of processing relating to such have been suggested (e.g., Singer, 2000; Thorpe et al., 2001). The temporal characteristics of resonant brain networks, under the hypothesis of a functional separation from spatial mechanisms, can explain the temporal stability of representations as defined by Churchland (2002); see here above) despite the highly plastic and diffuse functional anatomy of the brain (Wall et al., 2002). Such stability is ensured by the dynamics of bottom-up patterns triggering neocortical excitatory activity and matched in time with top-down memory representations or expectation signals (Grossberg, 1999; Dresp-Langley and Durup, 2009; Cacha and Poznanski, 2014). The temporal dynamics of these brain activity patterns are driven by environmental pressure (relevance) toward functional interaction (e.g., Grossberg, 1999; Hari, 2017). Consciousness can also be understood in terms of changes that have occurred in time during phylogenesis. All vertebrates appear to be phenomenally and affectively conscious, function according to circadian cycles, and experience various states of being with dynamic transitions between different states of consciousness (Birch et al., 2020). In humans, however, the variety of higher-order states of consciousness described in the literature is not only larger (Fabbro et al., 2015), but also qualitatively different. So-called primary consciousness related to representations coding for perception, affect, and action (Edelman, 2003) are likely to be shared by all mammals, while higher-order consciousness linked to the interpretation of contents of primary consciousness, self-related awareness of past and future, and symbolic activities relating to language (Kotchoubey, 2018) is what makes humans unique. There is no doubt that conscious ability results from neural network development and processing resources within the physical boundaries of a brain. However, human consciousness transcends these underlying brain mechanisms. By changing and developing with experience, in interaction with other beings, society, and the physical world, it creates potential for mobilizing new resources beyond currently existing or known physical boundaries.

Consciousness Transcends Brain, Space, and Time

The capability of consciously shaping our lives within the world and of projecting them into a distant future, imagined but not yet real, is a critical aspect of fully evolved human consciousness (Natsoulas, 1999), and drives human creativity and the technological and cultural development of human societies (e.g., Fabbro et al., 2015). As pointed out earlier (Logan, 2007), when humans started living in complex communities where cooperation was a key to survival, through the maintenance of the camp fire among other things, consciousness may have emerged from a new complexity of human interaction. Consciousness may thus be seen as a specific form of energy, with a creative potential that can lead to directly observable changes, in other beings and in physical environments. Consciousness thereby has, or can have, the power to determine and/or change future non-physical (mental) states, in the *Self* and in others, and/or future physical states in the outside world. To clarify how we may link this form of energy to the brain on the one hand, and to human society and the physical world on the other, we may consider the following general definition:

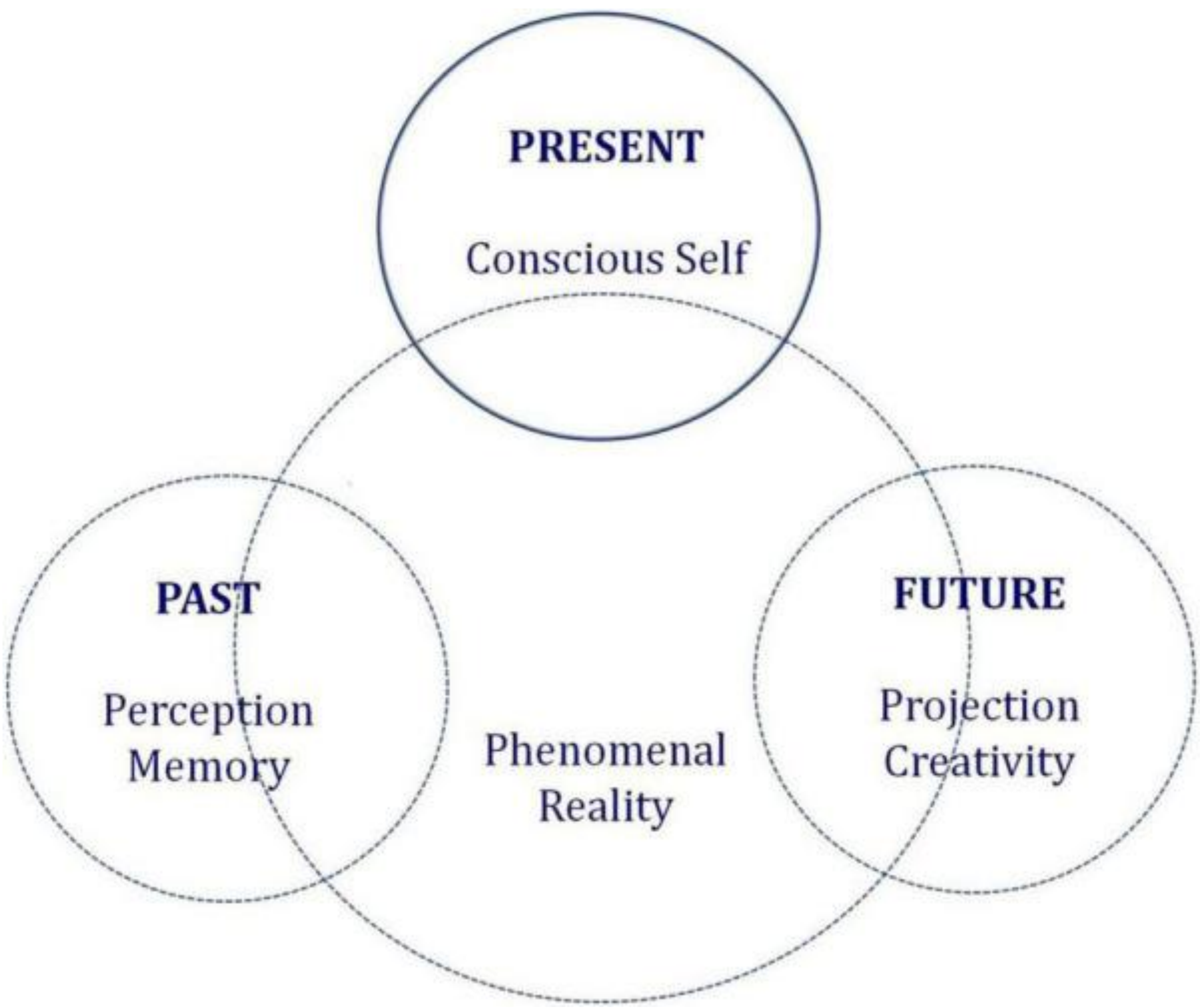
"Energy is the capacity for doing work. It may exist in potential, kinetic, thermal, electrical, chemical, nuclear, or other forms" (Encyclopedia Britannica, 2021).

The origin of conscious energy is definitely the brain, its form potential, and the work it does when operational is the work of producing change, in the *Self*, in other people, and in the world. Consciousness is thereby defined as the energy source of all change and creativity. The latter can be as diverse as the things we may observe, in ourselves, in others, and in the world. Consciousness enabled human creativity breaks currently known mental and physical barriers every day in art and science, finding new solutions to problems that previously appeared insurmountable. Phenomena such as consciously guided brain-to-brain communication (Grau et al., 2014) are now being investigated in respectable research laboratories. New particles that do not seem to obey conventional laws of physics have been discovered (Bazavov et al., 2014). Yet, our knowledge about the processes underlying this individual and collective power of consciousness is still very limited. Physical theory entails that the functioning of organisms or environments (living systems) is continuously challenged by the laws of thermodynamics in its attempt to maintain energy. Living organisms interact with each other and their environments in a continuously evolving process aimed at precisely that goal. With the evolution of the species, such interactions become increasingly sophisticated and effective. It is possible that consciousness, well beyond mere biological adaptive function (e.g., Jordan and Ghin, 2006; Kotchoubey, 2018) has evolved for the purpose of extending human capacity to, not only maintain, but create new energy. Interactionism thus becomes a key to understanding consciousness in terms of a product of the "transcendental human brain" (Cacha and Poznanski, 2014) or, in other words, a specific kind of temporally defined energy that results from interaction with space, but is not spatially defined or limited. As pointed out elsewhere (Pepperell, 2018), if we want to explain consciousness as a physical process we must acknowledge that, as in all physical processes, energetic activity is fundamental also to the processes that drive evolution and have produced consciousness. The nature of energy itself can take many different forms in physics. In the case of brain function, energy may be conceived in terms of the forces that produce specific electric activity dynamics (observable as brain waves) while we are conscious. By observing physical systems, we can understand how energy produces temporal change in systemic states on the basis of the observed differences between these systemic states. Consciousness as a transcendental form of energy, produced in the brain but not limited to the latter, produces temporal change in states of the *Self*, as suggested by current insights from studies on deep meditation. Meditative practice detunes the brain processes of self-awareness and blocks the instantiation of self-referential conscious states (Nair et al., 2017; Keppler, 2018). This leads to what has been called the "dissolution of the ego," which is not to be confounded with dissolution of consciousness (Keppler, 2018). Instead, deep meditative states tap into a wider spectrum of functional brain modes, opening the gates to extended phenomenal experience and expanded consciousness. The subject/object relationship, or relationship of the Self to its immediate environment during such a transcendental experience (Nair et al., 2017) is characterized by absence of a conscious perception of time passing, space, or body sense, in other words anything that would give meaning to conscious waking experience. Transcendental consciousness is described as full self-awareness isolated from the processes and objects of experience but characterized by the absence of sense of time, space, the physical body or the contents of perception that define waking experiences (Vieten et al., 2018; Paoletti and Ben-Soussan, 2020). The integration of transcendental experience with waking, dreaming, and sleeping has been labeled by distinct subjective and objective markers. It is subjectively marked by full self-awareness during waking, sleeping, or dreaming, greater emotional stability, decreased anxiety during challenging tasks and, physiologically, by the coexistence of specific brain wave patterns (Travis, 2014). Transcendental experience may be an engine that fuels human development and creates potential for the evolution of higher forms of human "intelligence," to be understood here in terms of mental capability. Insights from the neuroscience of meditation and its effects on human well-being and the development of higher forms of consciousness (Muehsam et al., 2017; Mahone et al., 2018; Vieten et al., 2018; Brandmeyer et al., 2019; Vivot et al., 2020) points toward states of enhanced consciousness in deep meditation as a crucial driver of human psychological development (Wahbeh et al., 2018). Deep meditation also has proven therapeutic effects, as in chronic pain management (Hilton et al., 2017) in individuals where consciousness is often reduced to little else than overwhelming sensations of pain, limiting the full, health expression of conscious capability in their everyday lives. One of the most controversial issues in vegetative state or a minimally conscious state syndromes concerns the potential capacity of such patients to continue to experience pain in the absence of any measurable self- or environmental awareness. Some of such patients might continue to experience elementary emotions or feelings, as suggested by results from neuroimaging studies showing activation of specific cerebral areas in response to situations which commonly generate empathy (Pistoia et al., 2013). In short, there are still more questions to be answered in consciousness research, well beyond what we call biological adaptation in the Darwinian tradition. For example, the intimate link between transcendental states of mind and a phenomenon called *eudaimonia* needs to be unraveled in well-targeted research across the human lifespan. This novel, largely uncharted terrain of scientific investigation into human consciousness may provide deeper insights into its function far more important to our species than biophysical explanations in terms of neural correlates, or biophysical fields. As pointed out by Churchland (2005), we have to, ultimately, ask ourselves what we want from a science of consciousness.

Eudaimonic Well-Being as a Window to the Purpose of Consciousness

Eudaimonia is a central concept in the Aristotelian philosophy of ethics. It is related to other concepts such as virtue, human excellence, and *phronesis*, which is an ethically grounded form of wisdom (cf. Walsh, 2015). The viewpoint on consciousness delivered here suggests potential for generating creative change, in non-physical (mental) states of the *Self*, of others, or in physical states as a neglected possibility for scientific investigation. The newly emerging field of research on eudamonic development (e.g., Rosenfeld, 2019; Alexander et al., 2021) can be linked to the clinical neuroscience of expanded consciousness (Paulson et al., 2017a,b; Vieten et al., 2018; Vivot et al., 2020) to generate new insights on how we can foster acceptance of what cannot be changed, in ourselves and in others. It could help us understand how expanding our consciousness can help us adjust our individual expectations, and find purpose and fulfillment despite adversity. A deeper understanding of consciousness in terms of practice (mindfulness, deep meditation) could help us understand the intuitive processes that enable us to think "outside the box," and to transcend the limitations of preconceived knowledge. Unconscious mechanism play an essential role in these intuitive processes (e.g., Grobstein, 2005; Dresp-Langley, 2011; Paulson et al., 2017a,b). Eudaimonia most certainly fuels on consciousness as energy potential, as a fundamental driving force toward a better life, referring to the subjective experiences associated with living a life of virtue and purpose in the pursuit of human excellence. The clinical neurosciences have only just begun to explore the underlying psychological and physiological mechanisms and processes. The phenomenological experiences derived from eudaimonic living include self-realization, self-actualization, personal expressiveness, optimism, vitality and, as experienced in states of deep meditation, capability of transcending the Self (Di Fabio and Palazzeschi, 2015). While hedonic well-being focuses on happiness defined in terms of pleasure and the avoidance of pain, the eudaimonic approach, on the other hand, relates to meaning and self-realization where well-being is seen as the full functioning of a person at a higher of consciousness than the one that seeks pleasure to attain happiness. A conscious Self in a state of eudaimonic well-being is focused on inner resources, resilience, higher meaning, authenticity, and purposefulness (Di Fabio and Palazzeschi, 2015; Cosco et al., 2017). Consciousness changes as our brains age, with changes in challenges to meet, and in perspectives for the future. Although younger individuals may be deemed more resilient than aging ones, this is a preconception that needs to be reconsidered in the current society context under the light of new challenges and problems related to current society contexts, the internet, and social media (e.g., Garland and Howard, 2018; Dresp-Langley, 2020; Liu et al., 2021). In aging individuals, on the other hand, changes in embodiment occur with aging neuronal mechanisms and their associated sensorimotor and cognitive deficits (Costello and Bloesch, 2017). Investigating the affective and cognitive mechanisms of deep meditation, mindfulness, and expanded consciousness at the behavioral, metabolic, and neurobiological levels, with research into the mechanisms of action underlying expanded consciousness, will no doubt contribute to the development of treatment options beyond age-related changes in neuronal function. A wider range of comprehensive approaches needs to be developed to address the multiple mechanisms underlying the many different conditions of breakdown of human resilience (e.g., Franklin et al., 2012). Such may be, but not always, related to brain aging. While embodiment changes as we age (Kuehn et al., 2018), these changes do not inevitably produce lesser well-being (Ryff et al., 2016). Yet, bodily awareness is a central component of human consciousness (Treves et al., 2019), and clearly an important aspect of well-being while we are young (Ginzburg et al., 2014). Resilience theory (e.g., Maltby et al., 2019) reflects the general idea that managing to navigate adversity and maintaining high levels of functioning across a large number of various domains demonstrates resilience, i.e., the capacity to cope with adversity. Similarly, traditional models of healthy aging (cf. Wong, 2018, for a review) suggest that having a high level of functioning across a large number of various domains would be a requirement for well-being and resilience. Yet, this may not necessarily be so. For example, health benefits have been identified among older adults who maintain a purposeful life engagement and thereby exhibit a high level of eudaimonic well-being (Cosco et al., 2017). These benefits would include extended longevity, reduced risks in various disease outcomes, reduced physiological deregulation, and gene expression linked to better inflammatory profiles (Ryff et al., 2016). Similarly, the brains of mindful or meditating individuals may be less affected by aging processes under the light of research suggesting that meditation and similar forms of mindfulness practice, or the states of expanded consciousness such practice generates, could contribute to preserving healthy brain tissue, cognitive and emotional resilience, and diminish the risk of dementia and other age-related neurodegenerative diseases (Kurth et al., 2017; Lutz et al., 2018). However, as already pointed out herein, the capability of projecting its own existence into a future that has not happened yet is the sole unique property of a fully conscious Self. Only the human primate has evolved this capability and, as postulated here, this capability is intimately linked to eudaimonic well-being as defined here above. This working assumption stems from the, previously discussed (Dresp-Langley, 2011, 2018; Dresp-Langley and Durup, 2012), ontological link between consciousness and time itself, which is summarized again in the context of this paper here, for illustration, in Figure 1. In the current societal context, with the many challenges we have to face and to anticipate, expanding our consciousness and exploiting it mindfully could be the key to our future as well as that of the whole planet. One of the most important functions of expanded consciousness may be its power to generate holistic resilience, to increase our potential to cope with new forms of adversity, whether we are young or old. A science of consciousness that leads to novel forms of well-being in the face of increasing adversity could have a significant impact, for individuals and for society as a whole.

FIGURE 1.



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All phenomenal reality originates from the ontological link between time and consciousness (after Dresp-Langley and Durup, 2012). This leads to consider consciousness as a form of creative energy beyond space and time, where specific cognitive abilities such as perception, memory or projective thinking and reasoning, although they may exploit conscious energy, need to be placed at a separate ontological level. An optimally expanded level of consciousness (by deep meditation or other mindfulness practice) would be equivalent to an expanded Self in a state of deep of sense of present, past, and future at one and the same moment in time. Such deep states of consciousness may not be attainable by our species.

Conclusion and Perspectives

Field theories of consciousness where the latter is seen as having duration and extension in space are limited by the fact that, unlike in the field theories in physics, particular regions of the presumed space-time continuum and interactions between elementary objects herein cannot be objectively measured, or accounted for mathematically. Libet (1993) was well aware of this fundamental problem by recognizing that “the mind field of consciousness” does not correspond to any category of known physical fields and cannot be observed directly by known physical means. Pockett (2013) wrote that “a field that is not observable directly by known physical means is in some danger of remaining confined to the realms of philosophy,” leaving it to her readers to decide whether this statement is to be considered as outrageous, or as a sign of a healthy sense of humor. Indeed, what strikes in all of the existing neural theories of consciousness including the field theories is the preconception that there has to be a “scientific” (as opposed to “philosophical”) account for consciousness. This is even more astonishing than the “astonishing hypothesis” (Crick, 1994) of a neural correlate for consciousness itself, because it means dismissing the fact that all contemporary science, including mathematics and physics, stems from nothing else but philosophy. Thus, quite ironically, the contemporary science of consciousness is based on the preconception that all reality has to be material in the sense of measurable by the known tools of physics, and that consciousness must be a direct product of physical activity in the brain. Yet, the biggest nut to crack for this kind of materialism has remained the existence of consciousness. It is the latter which has allowed to conceive all our methods and tools for scientific measurement, yet, it looks like these methods currently fail to fully explain what has made their conception possible in the first place. The full recognition that our conscious minds are not confined to our brains, or to what is currently measurable inside the brain or beyond, may eventually free contemporary neuroscience. Why look for a biophysical explanation of consciousness? Pressing society needs call for a science of consciousness in terms of its power to generate and foster eudaimonic well-being, of individuals as well as nations. Consciousness is above anything else an internal, dynamic process that governs intentionality for the purpose of creativity and social interaction and their complex relationships with the first-person perspective (e.g., Metzinger and Gallese, 2003). Thus, consciousness may have evolved to form a “mind field” that reaches beyond space and time to enable us, ultimately, to plan for both our survival, and our extinction (two essential and complementary concepts in Darwin’s theory of evolution) when survival on the planet is no longer an acceptable option for our species.

Data Availability Statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author/s.

Author Contributions

The author confirms being the sole contributor of this work and has approved it for publication.

Conflict of Interest

The author declares that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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The Neuroscience of Consciousness

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Conscious experience in humans depends on brain activity, so neuroscience will contribute to explaining consciousness. What would it be for neuroscience to explain consciousness? How much progress has neuroscience made in doing so? What challenges does it face? How can it meet those challenges? What is the philosophical significance of its findings? This entry addresses these and related questions.

To bridge the gulf between brain and consciousness, we need neural data, computational and psychological models, and philosophical analysis to identify principles to connect brain activity to conscious experience in an illuminating way. This entry will focus on identifying such principles without shying away from the neural details. The theories and data to be considered will be organized around constructing answers to two questions (see section 1.4 for more precise formulations):

- Generic Consciousness: How might neural properties explain when a state is conscious rather than not?
- Specific Consciousness: How might neural properties explain what the content of a conscious state is?

A challenge for an objective science of consciousness is to dissect an essentially subjective phenomenon. As investigators cannot experience another subject's conscious states, they rely on the subject's observable behavior to track consciousness. Priority is given to a subject's introspective reports as these express the subject's take on her experience. Introspection thus provides a fundamental way, perhaps *the* fundamental way, to track consciousness. That said, consciousness pervasively influences human behavior and affects physiological responses, so other forms of behavior and physiological data beyond introspective reports provide a window on consciousness. How to leverage disparate evidence is a central issue.

The term "neuroscience" covers those scientific fields whose explanations advert to the properties of neurons, populations of neurons, or larger parts of the nervous system.[1] This includes, but is not limited to, psychologists' and cognitive neuroscientists' use of various neuroimaging methods to monitor the activity of tens of millions of neurons, computational theorists' modeling of biological and artificial neural networks, neuroscientists' use of electrodes inserted into brain tissue to record neural activity from individual or populations of neurons, and clinicians' study of patients with altered conscious experiences in light of damage to brain areas. Given the breadth of neuroscience so conceived, this review focuses mostly on cortical activity that sustains perceptual consciousness, with emphasis on vision. This is not because visual consciousness is more important than other forms of consciousness. Rather, the level of detail in empirical work on vision often speaks more comprehensively to the issues that we shall confront.

That said, there are many forms of consciousness that we will not discuss. Some are covered in other entries such as split-brain phenomena (see the entry on the unity of consciousness, section 4.1.1), animal consciousness (see the entry on animal consciousness), and neural correlates of the will and agency (see the entry on agency, section 5). In addition, this entry will not discuss the neuroscience of consciousness in audition, olfaction, or gustation; disturbed consciousness in mental disorders such as schizophrenia; conscious aspects of pleasure, pain and the emotions; the phenomenology of thought; the neural basis of dreams; and modulations of consciousness during sleep and anesthesia among other issues. These are important topics, and the principles and approaches highlighted in this discussion will apply to many of these domains.

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1. Fundamentals

1.1 A Map of the Brain

The brain can be divided into the cerebral *cortex* and the *subcortex*. The cortex is divided into two hemispheres, left and right, each of which can be divided into four lobes: frontal, parietal, temporal and occipital.

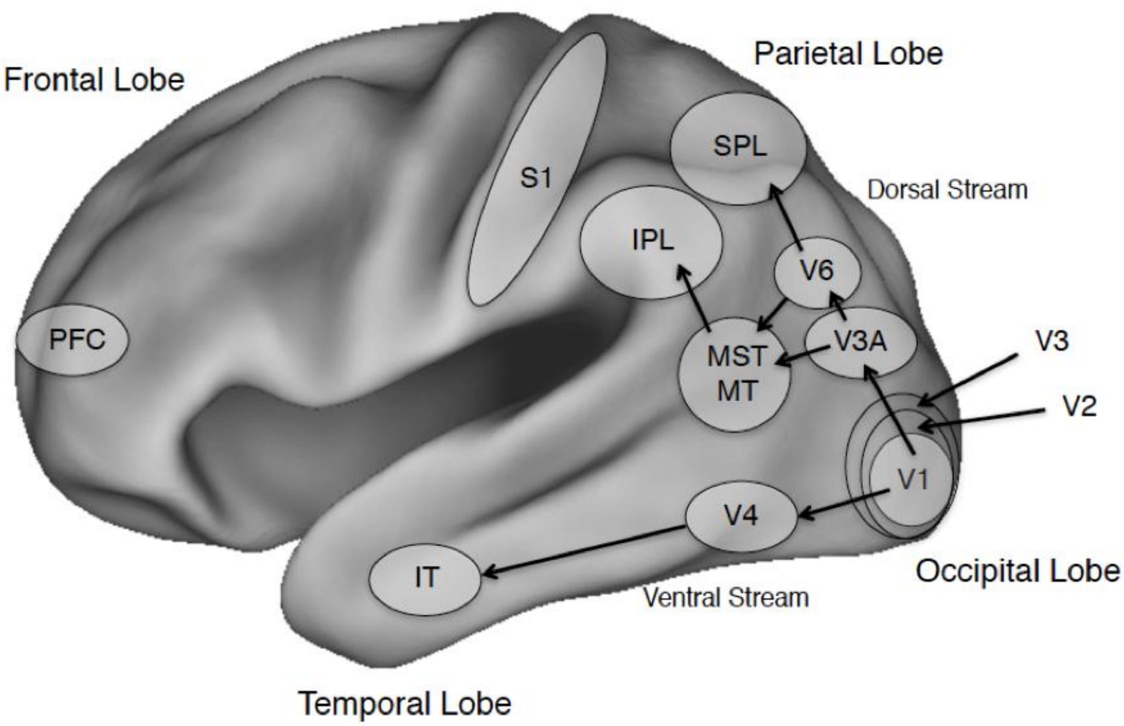

FIGURE 1. THE CEREBRAL CORTEX AND SALIENT AREAS

Figure Legend: The four lobes of the primate brain, shown for the left hemisphere. Some areas of interest are highlighted. Abbreviations: PFC: prefrontal cortex; IT: inferotemporal cortex; S1: primary somatosensory cortex; IPL and SPL: Inferior and Superior Parietal Lobule; MST: medial superior temporal visual area; MT: middle temporal visual area (also called V5 in humans); V1: primary visual cortex; V2-V6 consist of additional visual areas.

The discussion that follows will highlight specific areas of cortex including the *prefrontal cortex* that will figure in discussions of confidence (section 2.3), the global neuronal workspace (section 3.1) and higher order theories (section 3.3); the *dorsal visual stream* that projects into parietal cortex and the *ventral visual stream* that projects into temporal cortex including visual areas specialized for processing places, faces, and word forms (see sections 2.5 on places, 4.1 on visual agnosia and 5.3 on seeing words); *primary somatosensory cortex* S1 (see section 5.3.2 on tactile sensation); and early visual areas in the occipital cortex including the *primary visual area, V1* (see sections 4.2 on blindsight and 5.2 on binocular rivalry) and a motion sensitive area *V5*, also known as the *middle temporal area* (MT; section 5.3.1 on seeing motion). Beneath the cortex is the subcortex, divided into the forebrain, midbrain, and hindbrain, which covers many regions although our discussion will largely touch on the *superior colliculus* and the *thalamus*. The latter is critical for regulating wakefulness and general arousal, and both areas play an important role in visual processing.

1.2 Neurons and Brain

A neuroscientific explanation of consciousness adduces properties of the brain, typically the brain's electrical properties. A salient phenomenon is neural signaling through *action potentials* or *spikes*. A spike is a large change in electrical potential across a neuron's cellular membrane which can be transmitted between neurons that form a neural circuit. For a sensory neuron, the spikes it generates are tied to its *receptive field*. For example, in a visual neuron, its receptive field is understood in spatial terms and corresponds to that area of external space where an appropriate stimulus triggers the neuron to spike. Given this correlation between stimulus and spikes, the latter carries information about the former. Information processing in sensory systems involves processing of information regarding stimuli within receptive fields.

Which electrical property provides the most fruitful explanatory basis for understanding consciousness remains an open question. For example, when looking at a single neuron, neuroscientists are not interested in spikes per se but the spike rate generated by a neuron per unit time. Yet spike rate is one among many potentially relevant neural properties. Consider the blood oxygen level dependent signal (BOLD) measure in functional magnetic resonance imaging (fMRI). The BOLD signal is a measure of changes in blood flow in the brain when neural tissue is active and is postulated to be a function of post-synaptic activity while spikes are tied to presynaptic activity. Furthermore, neuroscientists are often not interested in the response of a single neuron but rather that of a population of neurons, of whole brain regions, and/or their interactions. Higher order properties of brain regions include the *local field potential* generated by populations of neurons and correlated activity such as *synchrony* between activity in different areas of the brain as measured by, for example, electrocorticography (EEG).

The number of neural properties potentially relevant to explaining mental phenomena is dizzying. This review focuses on the facts that neural sensory systems carry information about the subject's environment and that neural information processing can be tied to a notion of *neural representation*. How precisely to understand neural representation is itself a vexed question (Cao 2012, 2014; Shea 2014; Baker, Lansdell, & Kording 2022), but we will deploy a simple assumption with respect to spikes which can be reconfigured for other properties: where a sensory neuron generates spikes when a stimulus is placed in its receptive field, the spikes carry information about the stimulus. The sensory neuron's activity thus *represent* the relevant aspect of the stimulus that drives its response (e.g., direction of motion or intensity of a sound).[2] We shall return to neural representation in the final section when discussing how neural representations might explain conscious contents.

1.3 Access Consciousness and Phenomenal Consciousness

An important distinction separates *access consciousness* from *phenomenal consciousness* (Block 1995). "Phenomenal consciousness" refers to those properties of experience that correspond to *what it is like* for a subject to have those experiences (Nagel 1974 and the entry on qualia). These features are apparent to the subject from the inside, so tracking them arguably depends on one's having the relevant experience. For example, one understands what it is like to see red only if one has visual experiences of the relevant type (Jackson 1982).

As noted earlier, introspection is the first source of evidence about consciousness. Introspective reports bridge the subjective and objective. They serve as a behavioral measure that expresses the subject's own take on what it is like for them in having an experience. While there have been recent concerns about the reliability or empirical usefulness of introspection (Schwitzgebel 2011; Irvine 2012a), there are plausibly many contexts where introspection is reliable (Spener 2015; Wu 2023: chap. 7; see Irvine 2012b for an extended discussion of introspection in consciousness science; for philosophical theories, see Smithies & Stoljar 2012).

Introspective reports demonstrate that the subject can access the targeted conscious state. That is, the state is *access*-conscious: it is accessible for use in reasoning, report, and the control of action. Talk of access-consciousness must keep track of the distinction between *actual* access versus *accessibility*. When one reports on one's conscious state, one accesses the state. Thus, access consciousness provides much of the evidence for empirical theories of consciousness. Still, it seems plausible that a state can be conscious even if one does not access it in report so long as that state is *accessible*. One *can* report it. Access-consciousness is usually defined in terms of this dispositional notion of accessibility.

We must also consider the type of access/accessibility. Block's original characterization of access-consciousness emphasized accessibility in terms of the *rational* control of behavior, so we can summarize his account as follows:

A representation is access-conscious if it is poised for free use in reasoning and for direct "rational" control of action and speech.

Rational access contrasts with a broader conception of *intentional* access that takes a mental state to be access-conscious if it can inform goal-directed or intentional behavior including behavior that is not rational or done for a reason. This broader notion allows for additional measurable behaviors as relevant in assessing phenomenal consciousness especially in non-linguistic animals, non-verbal infants, and non-communicative patients. So, if access provides us with evidence for phenomenal consciousness, this can be (a) through introspective reports; (b) through rational behavior, (c) through intentional behavior including nonrational behavior. Indeed, in certain contexts, reflexive behavior and autonomic physiological measures provide measures of consciousness (section 2.2).

1.4 Generic and Specific Consciousness

There are two ways in which consciousness is understood in this entry. The first focuses on a mental state's *being conscious* in general as opposed to not being conscious. Call this property *generic consciousness*, a property shared by specific conscious states such as seeing a red rose, feeling a touch, or being angry. Thus:

Generic Consciousness: What conditions/states N of nervous systems are necessary and/or sufficient for a mental state, M, to be conscious as opposed to not?

If there is such an N, then the presence of N entails that an associated mental state M is conscious and/or its absence entails that M is unconscious.

A second focus will be on the content of consciousness, say that associated with a perceptual experience's being of some perceptible X. This yields a question about specific contents of consciousness such as experiencing the motion of an object (see section 5.3.1) or a vibration on one's finger (see section 5.3.2):

Specific Consciousness: What neural states or properties are necessary and/or sufficient for a conscious perceptual state to have content X rather than Y?

In introspectively accessing their conscious states, a subject reports what their experience is like by reporting what they experiences. Thus, the subject can report seeing an object moving, changing color, or being of a certain kind (e.g., a mug) and thus specify the content of the perceptual state. Discussion of specific consciousness will focus on perceptual states described as consciously perceiving X where X can be a particular such as a face or a property such as the color of an object.

Posing a clear question involves grasping its possible answers and in science, this is informed by identifying experiments that can provide evidence for such answers. The emphasis on necessary and sufficient conditions in our two questions indicates how to empirically test specific proposals. To test sufficiency, one would aim to produce or modulate a certain neural state and then demonstrate that consciousness of a certain form arises. To test necessity, one would eliminate a certain neural state and demonstrate that consciousness is abolished. Notice that such tests go beyond mere correlation between neural states and conscious states (see section 1.6 on neural correlates and sections 2.2, 4 and 5 for tests of necessity and sufficiency).

In many experimental contexts, the underlying idea is *causal* necessity and sufficiency. However, if $A = B$, then A's presence is also necessary and sufficient for B's presence since they are identical. Thus, a brain lesion that eliminates N and thereby eliminates conscious state S might do so either because N is causally necessary for S or because $N = S$. An intermediate relation is that N *constitutes* or *grounds* S which does not imply that N = S (see the entry on metaphysical grounding). Whichever option holds for S, the first step is to find N, a neural correlate of consciousness (section 1.6).

In what follows, to explain generic consciousness, various global properties of neural systems will be considered (section 3) as well as specific anatomical regions that are tied to conscious versus unconscious vision as a case study (section 4). For specific consciousness, fine-grained manipulations of neural representations will be examined that plausibly shift and modulate the contents of perceptual experience (section 5).

1.5 The Hard Problem

David Chalmers presents the hard problem as follows:

It is undeniable that some organisms are subjects of experience. But the question of how it is that these systems are subjects of experience is perplexing. Why is it that when our cognitive systems engage in visual and auditory information-processing, we have visual or auditory experience: the quality of deep blue, the sensation of middle C? How can we explain why there is something it is like to entertain a mental image, or to experience an emotion? It is widely agreed that experience arises from a physical basis, but we have no good explanation of why and how it so arises. Why should physical processing give rise to a rich inner life at all? It seems objectively unreasonable that it should, and yet it does. If any problem qualifies as *the* problem of consciousness, it is this one. (Chalmers 1995: 212)

The Hard Problem can be specified in terms of generic and specific consciousness (Chalmers 1996). In both cases, Chalmers argues that there is an inherent limitation to empirical explanations of phenomenal consciousness in that empirical explanations will be fundamentally either structural or functional, yet phenomenal consciousness is not reducible to either. This means that there will be something that is left out in empirical explanations of consciousness, a missing ingredient (see also the *explanatory gap* [Levine 1983]).

There are different responses to the hard problem. One response is to sharpen the explanatory targets of neuroscience by focusing on what Chalmers calls *structural features* of phenomenal consciousness, such as the spatial structure of visual experience, or on the contents of phenomenal consciousness. When we assess explanations of specific contents of consciousness, these focus on the neural representations that fix conscious contents. These explanations leave open exactly what the secret ingredient is that shifts a state with that content from unconsciousness to consciousness. On ingredients explaining generic consciousness, a variety of options have been proposed (see section 3), but it is unclear whether these answer the Hard Problem, especially if any answer to that the Problem has a necessary condition that the explanation must conceptually close off certain possibilities, say the possibility that the ingredient could be added yet consciousness not ignite as in a zombie, a creature without phenomenal consciousness (see the entry on zombies). Indeed, some philosophers deny the hard problem (see Dennett 2018 for a recent statement). Patricia Churchland urges: “Learn the science, do the science, and see what happens” (Churchland 1996: 408).

Perhaps the most common attitude for neuroscientists is to set the hard problem aside. Instead of explaining the existence of consciousness in the biological world, they set themselves to explaining generic consciousness by identifying neural properties that can turn consciousness on and off and explaining specific consciousness by identifying the neural representational basis of conscious contents.

1.6 Neural Correlates of Consciousness

Modern neuroscience of consciousness has attempted to explain consciousness by focusing on *neural correlates of consciousness* or NCCs (Crick & Koch 1990; LeDoux, Michel, & Lau 2020; Morales & Lau 2020). Identifying correlates is an important first step in understanding consciousness, but it is an early step. After all, correlates are not necessarily explanatory in the sense of answering specific questions posed by neuroscience. That one does not want a mere correlate was recognized by Chalmers who defined an NCC as follows:

An NCC is a minimal neural system *N* such that there is a mapping from states of *N* to states of consciousness, where a given state of *N* is sufficient under conditions *C*, for the corresponding state of consciousness. (Chalmers 2000: 31)

A similar way of putting this is that an NCC is “the minimal set of neuronal events and mechanisms jointly sufficient for a specific conscious percept” (Koch 2004: 16). One wants a minimal neural system since, crudely put, the brain is sufficient for consciousness but to point this out is hardly to explain consciousness even if it provides an answer to questions about sufficiency. There is, of course, much more to be said that is informative even if one does not drill down to a “minimal” neural system which is tricky to define or operationalize (see Chalmers 2000 for discussion; for criticisms of the NCC approach, see Noë & Thompson 2004; for criticisms of Chalmers’ definition, see Fink 2016).

The emphasis on sufficiency goes beyond mere correlation, as neuroscientists aim to answer more than the question: What is a neural correlate for conscious phenomenon *C*? For example, Chalmers’ and Koch’s emphases on sufficiency indicate that they aim to answer the question: What neural phenomenon is sufficient for consciousness? Perhaps more specifically: What neural phenomenon is causally sufficient for consciousness? Accordingly, talk of “correlate” is unfortunate since sufficiency implies correlation but not vice versa. After all, assume that the NCC is type identical to a conscious state. Then many neural states will correlate with the conscious state: (1) the NCC’s typical effects, (2) its typical causes, and (3) states that are necessary for the NCCs obtaining (e.g., the presence of sufficient oxygen). Thus, some correlated effects will not be explanatory. For example, citing the effects of consciousness will not provide causally sufficient conditions for consciousness.

Establishing necessary conditions for consciousness is also difficult. Neuroplasticity, redundancy, and convergent evolution make necessity claims extremely hard to support experimentally. Under normal conditions, healthy humans may require certain brain areas or processes for supporting consciousness. However, this does not mean those regions or processes are necessary in any strong metaphysical sense. For example, after a lesion, the brain's functional connections may change allowing a different structural support for consciousness to emerge. There is also nothing in the cortical arrangement of specialized regions that fix them to a particular function. The so-called "visual cortex" is recruited in blind individuals to perform auditory, numerical, and linguistic processing (Bedny 2017). Similarly, as with many other complex structures, the brain is highly redundant. Different areas may perform the same function, preventing any single one from being strictly necessary. Finally, the way in which the mammalian brain operates is not the only way to support awareness. Birds—as well as cephalopods and insects (Barron & Klein 2016; Birch, Schnell, & Clayton 2020)—and even other primates have different anatomical and functional neural mechanisms and yet their nervous systems may support consciousness (Nieder, Wagener, & Rinnert 2020). Thus, there may not be a single necessary structure or process for supporting conscious awareness.

While many theorists are focused on explanatory correlates, it is not clear that the field has always grasped this, something recent theorists have been at pains to emphasize (Aru et al. 2012; Graaf, Hsieh, & Sack 2012). In other contexts, neuroscientists speak of the neural *basis* of a phenomenon where the basis does not simply correlate with the phenomenon but also explains and possibly grounds it. However, talk of correlates is entrenched in the neuroscience of consciousness, so one must remember that the goal is to find the subset of neural correlates that are explanatory, in answering concrete questions. Reference to neural correlates in this entry will always mean neural explanatory correlates of consciousness (on occasion, we will speak of these as the neural *basis* of consciousness). That is, our two questions about specific and generic consciousness focus the discussion on neuroscientific theories and data that contribute to explaining them. This project allows that there are limits to neural explanations of consciousness, precisely because of the explanatory gap (Levine 1983).

2. Methods for Tracking Consciousness

Since studying consciousness requires that scientists track its presence, it will be important to examine various methods used in neuroscience to isolate and probe conscious states.

2.1 Introspection and Report

Scientists primarily study phenomenal consciousness through subjective reports; objective measures such as performance in a task are often used too (for a critical assessment, see Irvine 2013). We can treat reports in neuroscience as conceptual in that they express how the subject recognizes things to be, whether regarding what they perceive (perceptual or observational reports, as in psychophysics) or regarding what mental states they are in (introspective reports). A report's conceptual content can be conveyed in words or other overt behavior whose significance is fixed within an experiment (e.g., pressing a button to indicate that a stimulus is present or that one sees it). Subjective reports of conscious states draw on distinctively first-personal access to that state. The subject *introspects*.

Introspection raises questions that science has only recently begun to address systematically in large part because of longstanding suspicion regarding introspective methods or, in contrast, because of an unquestioning assumption that introspection is largely and reliably accurate. Early modern psychology relied on introspection to parse mental processes but ultimately abandoned it due to worries about introspection's reliability (Feest 2012; Spener 2018). Introspection was judged to be an unreliable method for addressing questions about mental processing (and it is still seen with suspicion by some; Schwitzgebel 2008). To address these worries, we must understand how introspection works, but unlike many other psychological capacities, detailed models of introspection of consciousness are hard to develop (Feest 2014; for theories of introspecting propositional attitudes, see Nichols & Stich 2003; Heal 1996; Carruthers 2011). This makes it difficult to address long-standing worries about introspective reliability regarding consciousness.

In science, questions raised about the reliability of a method are answered by calibrating and testing the method. This calibration has not been done with respect to the type of introspection commonly practiced by philosophers. Such introspection has revealed many phenomenal features that are targets of active investigation such as the phenomenology of mineness (Ehrsson 2009), sense of agency (Bayne 2011; Vignemont & Fourneret 2004; Marcel 2003; Horgan, Tienson, & Graham 2003), transparency (Harman 1990; Tye 1992), self-consciousness (Kriegel 2003: 122), cognitive phenomenology (Bayne & Montague 2011); phenomenal unity (Bayne & Chalmers 2003) among others. A scientist might worry that philosophical introspection merely recycles rejected methods of a century ago, indeed without the stringent controls or training imposed by earlier psychologists. How can we ascertain and ensure the reliability of introspection in the empirical study of consciousness?

Model migration, applying well-understood concepts in less well-understood domains, provides conceptual resources to reveal patterns across empirical systems and to promote theoretical insights (Lin 2018; Knuuttila & Loettgers 2014; see the entry on models in science). Introspection's range of operation and its reliability conditions—when and why it succeeds and when and why it fails—can be calibrated by drawing parallels to how Signal Detection Theory (SDT) models perception (see Dołęga 2023 for an evaluation of introspective theories). In SDT (Tanner & Swets 1954; Hautus, Macmillan, & Creelman 2021), perceptually detecting or discriminating a stimulus is the joint outcome of the observer's perceptual sensitivity (e.g., how well a perceptual system can tell signal from noise) and a decision to classify the available perceptual evidence as signal or not (i.e., observers set a response criterion for what counts as signal). Consider trying to detect something moving in the brush at twilight versus at noon. In the latter, the signal will be greatly separated from noise (the object will be easier to detect because it generates a strong internal perceptual response). In contrast, at twilight the signal will not be easy to disentangle from noise (the object will be harder to detect because of the weaker internal perceptual response it generates in the observer). Importantly, even at noon when the signal is strong, rare as they might be, misses and false alarms are to be expected. Yet in either case, one might operate with a conservative response criterion, say because one is afraid to be wrong. Thus, even if the signal is detectable, one might still opt not to report on it given a *conservative* bias (criterion), say if one is in the twilight scenario and would be ridiculed for "false alarms", i.e., claiming the object to be present when it is not.

Introspection can be modeled as a signal detection mechanism that operates over conscious states. Pains can be strong or weak, mental images can be vivid or faint, and perceptions can be more or less striking. In other words, conscious experiences admit degrees of intensity (Lee 2023; Morales 2023). According to introspective Signal Detection Theory or iSDT (Morales forthcoming), the intensity of conscious experiences (their mental strength) modulates the introspective internal response generated by the intensity of the conscious experience under examination, which in turn modulates introspective sensitivity. Everything else being equal, introspectors are more likely to introspect accurately an intense experience (e.g., a strong pain, a vivid mental image, etc.) than a weak experience (e.g., a mild pain, a faint mental image, etc.). As in perception, a biased introspective criterion may affect an introspector's response without necessarily implying changes in the introspectability of a state. Even when rare, introspection errors (misses and false alarms) should be possible and in fact expected. By modeling introspection as any other detection mechanism, iSDT aims to explain the range of reliability of introspection while preserving our intuitions that it provides highly accurate judgments in familiar cases such as detecting severe pain while also accounting for introspection's potential fallibility.

Thus, in the context of scientific experiments of consciousness, iSDT provides a model that predicts higher introspective reliability when judging strong experiences. When the experiences are weak—as one may expect from stimuli presented quickly and at threshold—introspective judgments are expected to be more unreliable (Dijkstra & Fleming 2023).

Another way to link scientific introspection to consciousness is to connect it to models of attention. Philosophical conceptions of introspective attention construe it as capable of directly focusing on phenomenal properties and experiences. As this idea is fleshed out, however, it is clearly not a form of attention studied by cognitive science, for the posited direct introspective attention is neither perceptual attention nor what psychologists call internal attention (e.g., the retrieval of thought contents as in memory recollection; Chun, Golomb, & Turk-Browne 2011). Calibrating introspection as it is used in the science of consciousness would benefit from concrete models of introspection (Chirimuuta 2014; Spener 2015; Wu 2023; Kammerer & Frankish 2023; Morales forthcoming).

We can draw inspiration from a proposal inspired by Gareth Evans (1982): in introspecting perceptual states, say judging that one sees an object, one draws on the same perceptual capacities used to answer the question whether the object is present. In introspection, one then appends a further concept of "seeing" to one's perceptual report.[3] Thus, instead of simply reporting that a red stimulus is present, one reports that one sees the red stimulus. Paradoxically, introspection relies on externally directed perceptual attention, but as noted earlier, identifying what one perceives is a way of characterizing what one's perception is like, so this "outward" perspective can provide information about the inner.

Further, the advantage of this proposal is that questions of reliability come down to questions of the reliability of psychological capacities that can be empirically assessed, say perceptual, attentional and conceptual reliability. For example, Peters and Lau (2015) showed that accuracy in judgments about the visibility of a stimulus, the introspective measure, coincided with accuracy in judgments about stimulus properties, the objective measure (see also Rausch & Zehetleitner 2016). Further, in many of the examples to be discussed, the perceptual attention-based account provides a plausible cognitive model of introspection (Wu, 2023). Subjects report on what they perceptually experience by attending to the object of their experience, and where perception and attention are reliable, a plausible hypothesis is that their introspective judgments will be reliable as well. Accordingly, the reliability of introspection in the empirical studies to be discussed can be assumed. Still, given that no scientist should assert the reliability of a method without calibration, introspection must be subject to the same standards. There is more work to be done.

2.2 Access Consciousness and No-Report Paradigms

Introspection illustrates a type of cognitive access, for a state that is introspected is access conscious. This raises a question that has epistemic implications: is access consciousness necessary for phenomenal consciousness? If it is not, then there can be phenomenal states that are not access conscious, so are in principle not reportable. That is, phenomenal consciousness can *overflow* access consciousness (Block 2007).

Access is tied to attention, and attention is tied to report. Some views hold that attention is necessary for access, which entails phenomenal consciousness (e.g., the Global Workspace theory [section 3.1]).[4] In contrast, other theories (e.g., recurrent processing theory section 3.2]), hold that there can be phenomenal states that are not accessible.

Many scientists of consciousness take there to be evidence for no phenomenal consciousness without access and little if no evidence of phenomenal consciousness outside of access. While those antagonistic to overflow have argued that it is not empirically testable (Cohen & Dennett 2011) testing that attention is necessary for consciousness may be equally untestable. After all, we must eliminate attention to a target while gathering evidence for the absence of consciousness. Yet if gathering evidence for consciousness requires attention, then in fulfilling the conditions for testing the necessity of attention, we undercut the access needed to substantiate the absence of (Wu 2017; for a monograph length discussion of attention and consciousness, see Montemayor & Haladjian 2015).[5] How then can we gather the required evidence to assess competing theories?

One response is to draw on *no-report paradigms* which measure reflexive behaviors correlated with conscious states to provide a window on the phenomenal that is independent of access (Lumer & Rees 1999; Tse et al. 2005). In binocular rivalry paradigms (see section 5.2), researchers show subjects different images to each eye. Due to their very different features, these images cannot be fused into a single percept. This results in alternating experiences that transition back and forth between one image and the other. Since the presented images remain constant while experience changes, binocular rivalry has been used to find the neural correlates of consciousness (see Zou, He, & Zhang 2016; and Giles, Lau, &

Odegaard 2016 for concerns about using binocular rivalry for studying the neural correlates of consciousness). However, binocular rivalry tasks have typically involved asking subjects to report what their experience is like, requiring the recruitment of attention and explicit report. To overcome this issue, Hesse & Tsao (2020) recently introduced an important variation by adding a small fixation point on different locations of each image. For example, subjects' right eye was shown a photo of a person with a fixation point drawn on the bottom of the image, and their left eye was presented with a photo of some tacos with a fixation point on the top. People and monkeys were trained to look at the fixation point while ignoring the image. This way, the experimenters could use their eye movement behavior as a proxy for which image they were experiencing without having to collect explicit reports: if subjects look up, they are experiencing the tacos; if they look down, they are experiencing the person. They confirmed with explicit reports from humans that both monkeys and humans in the no-report condition behaved similarly. Importantly, they found from single-cell recordings in the monkeys that neurons in inferotemporal cortex—a downstream region associated with high-level visual processing—represented the experienced image. Because these monkeys were never trained to report their percept (they were just following the fixation point wherever it was), the experimenters could more confidently conclude that the activity linked to the alternating images was due to consciously experiencing them and not due to introspecting or reporting.

No-report paradigms use indirect responses to track the subject's perceptual experience in the absence of explicit (conceptualized) report. These can include eye movements, pupil changes, electroencephalographic (EEG) activity or galvanic skin conductance changes, among others. No-report paradigms seem to provide a way to track phenomenal consciousness even when access is eliminated. This would broaden the evidential basis for consciousness beyond introspection and indeed, beyond intentional behavior (our "broad" conception of access). However, in practice they do not always result in drastically different results (Michel & Morales 2020). Moreover, they do not fully circumvent introspection (Overgaard & Fazekas 2016). For example, the usefulness of any indirect physiological measure depends on validating its correlation with alternating experience *given subjective reports*. Once it is validated, monitoring these autonomic responses can provide a way to substitute for subjective reports within that paradigm. One cannot, however, simply extend the use of no-report paradigms outside the behavioral contexts within which the method is validated. With each new experimental context, we must revalidate the measure with introspective report. Moreover, no-report paradigms do not match post-perceptual processing between conscious and unconscious conditions (Block 2019). Even if overt report is matched, the cognitive consequences of perceiving a stimulus consciously and failing to do so are not the same. For example, systematic reflections may be triggered by one stimulus (the person) but not the other (the tacos). These post-cognitive differences would generate different neural activity that is not necessarily related to consciousness. To avoid this issue, post-perceptual cognition would also need to be matched to rule out potential confounds (Block 2019). However, this is easier said than done and no uncontroversial solutions around this issue have been found (Phillips & Morales 2020; Panagiotaropoulos, Dwarakanath, & Kapoor 2020).

Can we use no report paradigms to address whether access is necessary for phenomenal consciousness? A likely experiment would be one that validates no-report correlates for some conscious phenomenon *P* in a concrete experimental context *C*. With this validation in hand, one then eliminates accessibility and attention with respect to *P* in *C*. If the no-report correlate remains, would this clearly support overflow? Perhaps, it could still be argued that the result does not rule out the possibility that phenomenal consciousness disappears with access consciousness *despite* the no-report correlate remaining. For example, the reflexive response and phenomenal consciousness might have a common cause that remains even if phenomenal consciousness is selectively eliminated by removing access.

2.3 Confidence and Metacognitive Approaches

Given worries about calibrating introspection, researchers have asked subjects to provide a different metacognitive assessment of conscious states via reports about *confidence* (Fleming 2023a, 2020; Pouget, Drugowitsch, & Kepecs 2016). A standard approach is to have subjects perform a task, say perceptual discrimination of a stimulus, and then report how *confident* they are that their perceptual judgment was accurate. This metacognitive judgment, a confidence rating, about perception can be assessed for accuracy by comparing it with perceptual performance (for discussion of formal methods such as metacognitive signal detection theory, see Maniscalco & Lau 2012, 2014). Related paradigms include post-decision wagering where subjects place wagers on specific responses as a way of estimating their confidence (Persaud, McLeod, & Cowey 2007; but see Dienes & Seth 2010).

There are some advantages of using confidence judgments for studying consciousness (Michel 2023; Morales & Lau 2022; Peters 2022). While standard introspective judgments about conscious experiences may capture more directly the phenomenon of interest, confidence judgments are easier to explain to subjects and they are also more interpretable from the experimenter's point of view. Confidence judgments provide an objective measure of *metacognitive sensitivity*: how well subjects' confidence judgments track their performance in the task. Subjects can also receive feedback on those ratings and, at least in principle, improve their metacognitive sensitivity (though this has proved hard to achieve in laboratory tasks; Rouy et al. 2022; Haddara & Rahnev 2022). Metacognitive judgments also have the advantage over direct judgments about conscious experiences (e.g., Ramsøy & Overgaard 2004) in that they allow for comparisons between different domains that have very different phenomenology (e.g., perception vs memory) (e.g., Gardelle, Corre, & Mamassian 2016; Faivre et al. 2017; Morales, Lau, & Fleming 2018; Mazancieux et al. 2020).

One concern with metacognitive approaches is that they also rely on introspection (Rosenthal 2019; see also Sandberg et al. 2010; Dienes & Seth 2010). If metacognition relies on introspection, does it not accrue all the disadvantages of the latter? Perhaps, but an important gain in metacognitive approaches is that it allows for quantitative psychophysical analysis. While it does not replace introspection, it brings an analytical rigor to addressing certain aspects of conscious awareness.

How might we bridge metacognition with consciousness as probed by traditional introspection? The metacognitive judgment reflects introspective assessment of the quality of perceptual states and can provide information about the presence of consciousness. For example, Peters and Lau (2015) found that increases in metacognitive confidence tracked increases in perceptual sensitivity, which presumably underly the quality of perceptual experiences. They also did not find significant differences between asking for confidence or visibility judgments. Even studies that have found (small) differences between the two kinds of judgments indicate considerable association between the two ratings, suggesting similar behavioral patterns (Rausch & Zehetleitner 2016; Zehetleitner & Rausch 2013).

Beyond behavior, neuroscientific work shows that similar regions of the brain (e.g., prefrontal cortex) may be involved in supporting both conscious awareness and metacognitive judgments. Studies with non-human primates and rodents have begun to shed light on neural processing for metacognition (for reviews, see Grimaldi, Lau, & Basso 2015; Pouget, Drugowitsch, & Kepecs 2016). From animal studies, one theory is that metacognitive information regarding perception is already present in perceptual areas that guide observational judgments, and these studies implicate parietal cortex (Kiani & Shadlen 2009; Fetsch et al. 2014) and the superior colliculus (Kim & Basso 2008; but see Odegaard et al. 2018). Alternatively, information about confidence might be read out by other structures (see section 3.3 on Higher-Order Theory; also the entry on higher order theories of consciousness). In both human and animal studies, the prefrontal cortex (specifically, subregions in dorsolateral and orbitofrontal prefrontal cortex) has been found to support subjective reports of awareness (Cul et al. 2009; Lau & Passingham 2006), subjective appearances (Liu et al. 2019); visibility ratings (Rounis et al. 2010); confidence ratings (Fleming, Huijgen, & Dolan 2012; Shekhar & Rahnev 2018) and conscious experiences without reports (Mendoza-Halliday & Martinez-Trujillo 2017; Kapoor et al. 2022; Michel & Morales 2020).

2.4 The Intentional Action Inference

Metacognitive and introspective judgments result from intentional action, so why not look at intentional action, broadly construed, for evidence of consciousness? Often, when subjects perform perception guided actions, we infer that they are relevantly conscious. It would be odd if a person cooks dinner and then denies having seen any of the ingredients. That they did something intentionally provides evidence that they were consciously aware of what they acted on. An emphasis on intentional action embraces a broader evidential basis for consciousness. Consider the *Intentional Action Inference* to phenomenal consciousness:

If some subject acts intentionally, where her action is guided by a perceptual state, then the perceptual state is phenomenally conscious.

An epistemic version takes the action to provide good evidence that the state is conscious. Notice that introspection is typically an intentional action so it is covered by the inference. In this way, the Inference effectively levels the evidential playing field: introspective reports are simply one form among many types of intentional actions that provide evidence for consciousness. Those reports are not privileged.

The intentional action inference and no-report paradigms highlight that the science of consciousness has largely restricted its behavioral data to one type of intentional action, introspection. What is the basis of privileging one intentional action over others? Consider the calibration issue. For many types of intentional action deployed in experiments, scientists can calibrate performance by objective measures such as accuracy. This has not been formally done for introspection of consciousness, so scientists have privileged an uncalibrated measure over a calibrated one. This seems empirically ill-advised. On the flip side, one worry about the intentional action inference is that it ignores guidance by unconscious perceptual states (see sections 4 and 5.3.1).

2.5 Unresponsive Wakefulness Syndrome and the Intentional Action Inference

The Intentional Action Inference is operative when subjective reports are not available. For example, it is deployed in arguing that some patients diagnosed with unresponsive wakefulness syndrome are conscious (Shea & Bayne 2010; Drayson 2014).

A patient [with unresponsive wakefulness syndrome] appears at times to be wakeful, with cycles of eye closure and eye opening resembling those of sleep and waking. However, close observation reveals no sign of awareness or of a 'functioning mind': specifically, there is no evidence that the patient can perceive the environment or his/her own body, communicate with others, or form intentions. As a rule, the patient can breathe spontaneously and has a stable circulation. The state may be a transient stage in the recovery from coma or it may persist until death. (Working Party RCP 2003: 249)

These patients are not clinically comatose but fall short of being in a "minimally conscious state". Unlike unresponsive wakeful patients, minimally conscious state patients seemingly perform intentional actions.

Recent work suggests that some patients diagnosed with unresponsive wakeful syndrome are conscious. Owen et al. (2006) used fMRI to demonstrate correlated activity in such patients in response to commands to deploy imagination. In an early study, a young female patient was scanned by fMRI while presented with three auditory commands: "imagine playing tennis", "imagine visiting the rooms in your home", "now just relax". The commands were presented at the beginning of a thirty-second period, alternating between imagination and relax commands. The patient demonstrated similar activity when matched to control subjects performing the same task: sustained activation of the supplementary motor area (SMA) was observed during the motor imagery task while sustained activation of the parahippocampal gyrus including the parahippocampal place area (PPA) was observed during the spatial imagery task. Later work reproduced this result in other patients and in one patient, the tasks were used as a proxy for "yes"/ "no" responses to questions (Monti et al. 2010; for a review, see Fernández-Espejo & Owen 2013). Note that these tasks probe *specific* contents of consciousness by monitoring neural correlates of conscious imagery.

Several authors (Greenberg 2007; Nachev & Husain 2007) have countered that the observed activity was an automatic, non-intentional response to the command sentences, specifically to the words “tennis” and “house”. In normal subjects, reading action words is known to activate sensorimotor areas (Pulvermüller 2005). Owen and colleagues (2007), responded that the sustained activity over thirty-seconds made an automatic response less likely than an intentional response. One way to rule out automaticity is to provide the patient with different sentences such as “do *not* imagine playing tennis” or “*Sharlene* was playing tennis”. Owen et al. (2007) demonstrated that presenting “Sharlene was playing tennis” to a normal subject did not induce the same activity as when the subject obeyed the command “imagine playing tennis”, but the same intervention was not tried on patients. However, subsequent experiments using other measures such as EEG (Goldfine et al. 2011; Curley et al. 2018; Cruse et al. 2012) and functional connectivity (Demertzi et al. 2015), indicate conscious awareness is indeed present in patients with (wrongly diagnosed) unresponsive wakefulness syndrome (for a review, see Edlow et al. 2021; for ethical reflections around diagnosing awareness in patients with disorders of consciousness, see Young et al. 2021).

Owen et al. draw on a neural correlate of imagination, a mental action. Arguing that the neural correlate provides evidence of the patient’s executing an intentional action, they invoke a version of the Intentional Action Inference to argue that performance provides evidence for specific consciousness tied to the information carried in the brain areas activated.[6]

3. Neurobiological Theories of Consciousness

Recall that the Generic Consciousness question asks:

What conditions/states *N* of nervous systems are necessary and/or sufficient for a mental state, *M*, to be conscious as opposed to not?

Victor Lamme notes:

Deciding whether there is phenomenality in a mental representation implies putting a boundary—drawing a line—between different types of representations…We have to start from the intuition that consciousness (in the phenomenal sense) exists, and is a mental function in its own right. That intuition immediately implies that there is also *un*conscious information processing. (Lamme 2010: 208)

It is uncontroversial that there is unconscious information processing, say processing occurring in a computer. What Lamme means is that there are conscious and unconscious mental states (representations). For example, there might be visual states of seeing *X* that are conscious or not (section 4).

In what follows, the theories discussed provide higher level neural properties that are necessary and/or sufficient for generic consciousness of a given state. To provide a gloss on the hypotheses: For the Global Neuronal Workspace, entry into the neural workspace is necessary and sufficient for a state or content to be consciousness. For Recurrent Processing Theory, a type of recurrent processing in sensory areas is necessary and sufficient for perceptual consciousness, so entry into the Workspace is not necessary. For Higher-Order Theories, the presence of a higher-order state tied to prefrontal areas is necessary and sufficient for phenomenal experience, so recurrent processing in sensory areas is not necessary nor is entry into the workspace. For Information Integration Theories, a type of integration of information is necessary and sufficient for a state to be conscious.

3.1 The Global Neuronal Workspace

One explanation of generic consciousness invokes the *global neuronal workspace*. Bernard Baars first proposed the global workspace theory as a cognitive/computational model (Baars 1988), but we will focus on the neural version of Stanislas Dehaene and colleagues: a state is conscious when and only when it (or its content) is present in the global neuronal workspace making the state (content) globally *accessible* to multiple systems including long-term memory, motor, evaluational, attentional and perceptual systems (Dehaene, Kerszberg, & Changeux 1998; Dehaene & Naccache 2001; Dehaene et al. 2006). Notice that the previous characterization does not commit to whether it is phenomenal or access consciousness that is being defined.

Access should be understood as a relational notion:

A system *X* accesses content from system *Y* iff *X* uses that content in its computations/processing.

The *accessibility* of information is then defined as its potential access by other systems. Dehaene (Dehaene et al. 2006) introduces a threefold distinction: (1) neural states that carry information that is not accessible (*subliminal* information); (2) states that carry information that is accessible but not accessed (not in the workspace; *preconscious* information); and (3) states whose information is accessed by the workspace (*conscious* information) and is globally accessible to other systems. So, a necessary and sufficient condition for a state's being conscious rather than not is the access of a state or content by the workspace, making that state or content accessible to other systems. Hence, only states in (3) are conscious.

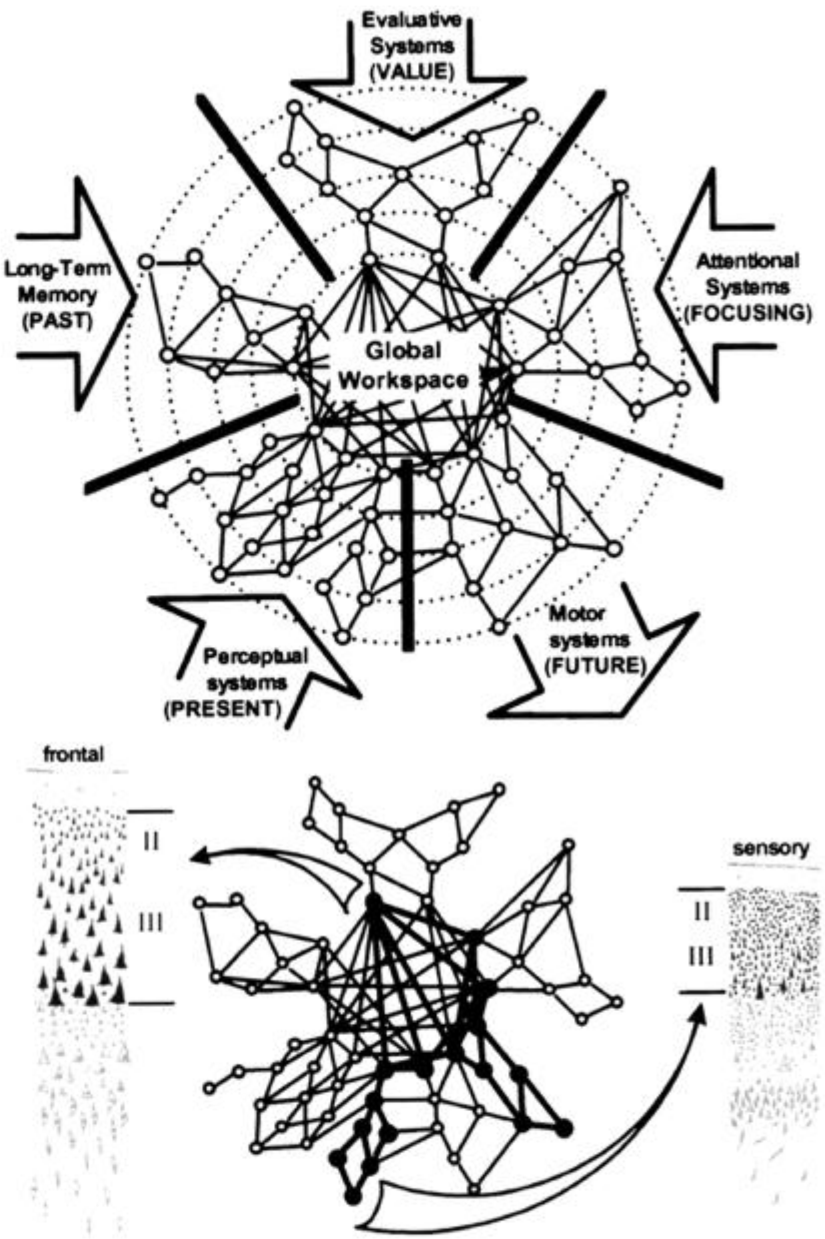

FIGURE 2. THE GLOBAL NEURONAL WORKSPACE

Figure Legend: The top figure provides a neural architecture for the workspace, indicating the systems that can be involved. The lower figure sets the architecture within the six layers of the cortex spanning frontal and sensory areas, with emphasis on neurons in layers 2 and 3. Figure reproduced from Dehaene, Kerszberg, and Changeux 1998. Copyright (1998) National Academy of Sciences.

The global neuronal workspace theory ties access to brain architecture. It postulates a cortical structure that involves workspace neurons with long-range connections linking systems: perceptual, mnemonic, attentional, evaluational and motoric.

What is the global workspace in neural terms? Long-range workspace neurons within different systems can constitute the workspace, but they should not necessarily be identified with *the* workspace. A subset of workspace neurons becomes the workspace when they exemplify certain neural properties. What determines which workspace neurons constitute the workspace at a given time is the activity of those neurons given the subject's current state. The workspace then is not a rigid neural structure but a rapidly changing neural network, typically only a proper subset of all workspace neurons.

Consider then a neural population that carries content *p* and is constituted by workspace neurons. In virtue of being workspace neurons, the content *p* is accessible to other systems, but it does not yet follow that the neurons then constitute the global workspace. A further requirement is that workspace neurons are (1) put into an active state that must be sustained so that (2) the activation generates a *recurrent* activity between workspace systems. Only when these systems are recurrently activated are they, along with the units that access the information they carry, constituents of the workspace. This activity accounts for the idea of global *broadcast* in that workspace contents are accessible to further systems. Broadcasting explains the idea of consciousness as *for the subject*: globally broadcasted content is accessible for the subject's use in informing behavior.

The global neuronal workspace theory provides an account of *access* consciousness but what of phenomenal consciousness? The theory predicts widespread activation of a cortical workspace network as correlated with phenomenal conscious experience, and proponents often appeal to imaging results that reveal widespread activation when consciousness is reported (Dehaene & Changeux 2011). There is, however, a potential confound. We track phenomenal consciousness by access in introspective report, so widespread activity during reports of conscious experience correlates with both access and phenomenal consciousness. Correlation cannot tell us whether the observed activity is the basis of phenomenal consciousness or of access consciousness in report (Block 2007). This remains a live question for as discussed in section 2.2, we do not have empirical evidence that overflow is false.

To eliminate the confound, experimenters ensure that performance does not differ between conditions where consciousness is present and where it is not. Where this was controlled, widespread activation was not clearly observed (Lau & Passingham 2006). Still, the absence of observed activity by an imaging technique does not imply the absence of actual activity for the activity might be beyond the limits of detection of that technique. Further, there is a general concern about the significance of null results given that neuroscience studies focused on prefrontal cortex are typically underpowered (for discussion, see Odegaard, Knight, & Lau 2017).

3.2 Recurrent Processing Theory

A different explanation ties perceptual consciousness to processing independent of the workspace, with focus on *recurrent* activity in sensory areas. This approach emphasizes properties of first-order neural representation as explaining consciousness. Victor Lamme (2006, 2010) argues that recurrent processing is necessary and sufficient for consciousness. Recurrent processing occurs where sensory systems are highly interconnected and involve feedforward and feedback connections. For example, forward connections from primary visual area V1, the first cortical visual area, carry information to higher-level processing areas, and the initial registration of visual information involves a forward sweep of processing. At the same time, there are many feedback connections linking visual areas (Felleman & Van Essen 1991), and later in processing, these connections are activated yielding dynamic activity within the visual system.

Lamme identifies four stages of normal visual processing:

- Stage 1: Superficial feedforward processing: visual signals are processed locally within the visual system.
- Stage 2: Deep feedforward processing: visual signals have travelled further forward in the processing hierarchy where they can influence action.
- Stage 3: Superficial recurrent processing: information has traveled back into earlier visual areas, leading to local, recurrent processing.
- Stage 4: Widespread recurrent processing: information activates widespread areas (and as such is consistent with global workspace access).

Lamme holds that recurrent processing in Stage 3 is necessary and sufficient for consciousness. Thus, what it is for a visual state to be conscious is for a certain recurrent processing state to hold of the relevant visual circuitry. This identifies the crucial difference between the global neuronal workspace and recurrent processing theory: the former holds that recurrent processing at Stage 4 is necessary for consciousness while the latter holds that recurrent processing at Stage 3 is sufficient. Thus, recurrent processing theory affirms phenomenal consciousness without access by the global neuronal workspace. In that sense, it is an overflow theory (see section 2.2).

Why think that Stage 3 processing is sufficient for consciousness? Given that Stage 3 processing is not accessible to introspective report, we lack introspective evidence for sufficiency. Lamme appeals to experiments with brief presentation of stimuli such as letters where subjects are said to report seeing more than they can identify in report (Lamme 2010). For example, in George Sperling's partial report paradigm (Sperling 1960), subjects are briefly presented with an array of 12 letters (e.g., in 300 ms presentations) but are typically able to report only three to four letters even as they claim to see more letters (but see Phillips 2011). It is not clear that this is strong motivation for recurrent processing, since the very fact that subjects can report seeing more letters shows that they have some access to them, just not access to letter identity.

Lamme also presents what he calls *neuroscience arguments.* This strategy compares two neural networks, one taken to be sufficient for consciousness, say the processing at Stage 4 as per Global Workspace theories, and one where sufficiency is in dispute, say recurrent activity in Stage 3. Lamme argues that certain features found in Stage 4 are also found in

Stage 3 and given this similarity, it is reasonable to hold that Stage 3 processing suffices for consciousness. For example, both stages exhibit recurrent processing. Global neuronal workspace theorists can allow that recurrent processing in stage 3 is correlated, even necessary, but deny that this activity is explanatory in the relevant sense of identifying sufficient conditions for consciousness.

It is worth reemphasizing the empirical challenge in testing whether access is necessary for phenomenal consciousness (sections 2.1–2.2). The two theories return different answers, one requiring access, the other denying it. As we saw, the methodological challenge in testing for the presence of phenomenal consciousness independently of access remains a hurdle for both theories.

3.3 Higher-Order Theory

A long-standing approach to conscious states holds that one is in a conscious state if and only if one relevantly represents oneself as being in such a state. For example, one is in a conscious visual state of seeing a moving object if and only if one suitably represents oneself being in that visual state. This higher-order state, in representing the first-order state that represents the world, results in the first order state's being conscious as opposed to not. The intuitive rationale for such theories is that if one were in a visual state but in no way aware of that state, then the visual state would not be conscious. Thus, to be in a conscious state, one must be aware of it, i.e., represent it (Rosenthal 2002; see the entry on higher order theories of consciousness). On certain higher-order theories (Higher-Order Thought Theory, Rosenthal 2005; and Higher-Order Representation of a Representation (HOROR), Brown 2015), one can be in a conscious visual state even if there is no visual system activity, so long as one represents oneself as being in that state (for a debate, see Block 2011; Rosenthal 2011). Other family of theories postulates that experiences are jointly determined by first- and higher-order states [e.g., Higher-Order State Space (HOSS) (Fleming 2020); Perceptual Reality Monitoring (PRM) (Lau 2019)]. An intermediate perspective proposes that higher-order states track our mental attitudes towards first-order states along different dimensions that include familiarity, vividness, value, and so on (Self-Organizing Meta-Representational Account (SOMA)—Cleeremans 2011; Cleeremans et al. 2020). These differences apart, higher-order theories merge with empirical work by tying high-order representations with brain activity, typically in the prefrontal cortex, which is taken to be the neural substrate of the required higher-order representations.

The focus on the prefrontal cortex allows for empirical tests of the higher-order theory against other accounts (Lau & Rosenthal 2011; LeDoux & Brown 2017; Brown, Lau, & LeDoux 2019; Lau 2022). For example, on the higher-order theory, lesions to prefrontal cortex should affect consciousness (see Kozuch 2013, 2022, 2023), testing the necessity of prefrontal cortex for consciousness. Against higher-order theories, some reports claim that patients with prefrontal cortex surgically removed maintain preserved perceptual consciousness (Boly et al. 2017) and that intracranial electrical stimulation (iES) to the prefrontal cortex does not alter consciousness (Raccah, Block, & Fox 2021). This would lend support to recurrent processing theories that hold that prefrontal cortical activity is not necessary for consciousness (and would be evidence against both GWT and higher-order theories). It is not clear, however, that the interventions succeeded in removing *all* of prefrontal cortex, leaving perhaps sufficient frontal areas needed to sustain consciousness (Odegaard, Knight, & Lau 2017), or that simple, localized stimulation to prefrontal cortex would be the right kind of stimulation for altering awareness (see Naccache et al. 2021). Bilateral suppression of prefrontal activity using transcranial magnetic stimulation also seems to selectively impair visibility as evidenced by metacognitive report (Rounis et al. 2010). Furthermore, certain syndromes and experimental manipulations suggest consciousness in the absence of appropriate sensory processing as predicted by some higher-order accounts (Lau & Brown 2019), a claim that coheres with the theory's sufficiency claims.

Subjective reports of conscious versus unconscious trials activate frontal regions as shown with EEG (Cul et al. 2009) and fMRI (Lau & Passingham 2006). Liu and colleagues (Liu et al. 2019) leveraged the "double-drift illusion" to show that real and apparent motion shared patterns of neural activity only in lateral and medial frontal cortex, not visual cortex. The double-drift illusion is a dramatic mismatch between physical and apparent motion created by a patch of gratings moving vertically while the gratings cycle horizontally; this creates the illusion of the patch's path to be more than 45º away from vertical. The conscious experience of seeing a stimulus veer off diagonally, whether physically or illusorily, was similarly encoded only in the prefrontal cortex, suggesting that the conscious experience of stimulus's diagonal motion was represented there, not in visual cortex. In a carefully designed no-report paradigm, Hatamimajoumerd and colleagues (2022) found that conscious stimuli were decodable from prefrontal cortex well above chance. Intracranial electrophysiological recording, where electrodes are placed directly on the surface of the brain, reveals prefrontal activity related to visual consciousness even when subjects were not required to respond to the stimulus (Noy et al. 2015). Fazekas and Nemeth (2018) discuss studies using different neuroimaging techniques showing significant increases in activity in the prefrontal cortex during dreams, a natural case of phenomenal awareness without report. Convergent evidence about the role of the prefrontal cortex sustaining awareness comes from single-cell recordings in macaques. Using binocular rivalry (see section 5.2), Dwarakanath et al. (2023) and Kapoor et al. (2022) show that dynamic subjective changes in monkeys' conscious experiences are robustly represented in prefrontal cortex.

3.4 Information Integration Theory

Information Integration Theory of Consciousness (IIT) draws on the notion of *integrated information*, symbolized by Φ, as a way to explain generic consciousness—specifically the quantity of consciousness present in a system (Tononi 2004, 2008; Oizumi, Albantakis, & Tononi 2014; Albantakis et al. 2023). IIT also aims to explain specific consciousness (i.e., the quality or content of conscious experiences) by appealing to the conceptual causal structure of the integrated information complex (i.e., the set of units of the physical substrate that is maximally integrated).

Integrated information theory (IIT) "starts from phenomenology and makes use of thought experiments to claim that consciousness is integrated information" (Tononi 2008: 216). IIT's first step is to find "*phenomenological* axioms", that is, immediately given essential properties of every conceivable experience. Once properly understood, these phenomenological axioms are taken by IIT to be irrefutably true (Albantakis et al. 2023: 3). These axioms, obtained by drawing on introspection and reason, are that consciousness exists, and that it is intrinsic, specific, unitary, definite, and structured. These axioms lead to postulates of *physical* existence. In other words, physical implementations that respect the properties first discovered through introspection. Finally, IIT develops mathematical formalisms that aim to preserve all these features and that can in principle help calculate the quality and quantity of integrated information in a system, or Φ.[7]

Integrated information is defined in terms of the effective information carried by the parts of the system in light of its causal profile. For example, consider a circuit (neuronal, electrical, or otherwise). We can focus on a part of the whole circuit, say two connected nodes, and compute the effective information that can be carried by this microcircuit. The system carries *integrated information* if the effective informational content of the whole is greater than the sum of the informational content of the parts. If there is no partitioning where the summed informational content of the parts equals the whole, then the system as a whole carries integrated information and it has a positive value for Φ. Intuitively, the interaction of the parts adds more to the system than the parts do alone.

IIT holds that an above-zero value for Φ implies that a system is conscious, with more consciousness going with greater values for Φ. For example, Tononi argues that the human cerebellum does not contribute to consciousness due to its highly modular anatomical organization. Thus, it is hypothesized that the cerebellum has a value of zero Φ despite there being four to five times the number of neurons in the cerebellum versus in the human cortex. On IIT, what matters is the presence of appropriate connections and not the number of neurons (the soundness of this argument about cerebellum has been contested; Aaronson 2014b; Merker, Williford, & Rudrauf 2022). For this same reason, IIT also makes counterintuitive predictions. From panpsychist conclusions, such as admitting that even a 2D grid of inactivated logic gates “doing absolutely nothing, may in fact have a large value of PHI” (Tononi 2014 in Other Internet Resources), to neuroscientifically implausible conclusions: “a brain where no neurons were activated, but were kept ready to respond in a differentiated manner to different perturbations, would be conscious (perhaps that nothing was going on)” (Tononi 2004). (In Other Internet Resources, see Aaronson 2014a and 2014b for striking counterexamples; see Tononi 2014 for a response).

It is important to note that IIT is not in and of itself a neuroscientific theory of consciousness. Rather, IIT is probably best understood as a metaphysical theory about the essential features of consciousness. Accordingly, these features could be present not just in organisms with neural systems but in any physical system (organic or not) that integrates information with a Φ larger than 0 (Tononi et al. 2016). Evidence of its metaphysical status are the theory’s idealist corollaries (see entry for Idealism). According to Tononi, and in stark contrast to current neuroscientific assumptions, only intrinsic entities (i.e., conscious entities) “truly exist and truly cause, whereas my neurons or my atoms neither truly exist nor truly cause” (Tononi, et al. 2022: 2 [Other Internet Resources]). Relatedly, IIT has received criticisms about its soundness and its neuroscientific status based on both empirical and theoretical arguments. One notable concern is the lack of clarity between IIT's metaphysical claims and their potential relevance for a neuroscientific understanding of consciousness.[8]

3.5 Frontal or Posterior?

In recent years, one way to frame the debate between theories of generic consciousness is whether the "front" or the "back" of the brain is crucial. Using this rough distinction allows us to draw the following contrasts: Recurrent processing theories focus on sensory areas (in vision, the "back" of the brain) such that where processing achieves a certain recurrent state, the relevant contents are conscious even if no higher-order thought is formed or no content enters the global workspace. Similarly, proponents of IIT have recently emphasized a "posterior hot zone" covering parietal and occipital areas as a neural correlate for consciousness, as they speculate that this zone may have the highest value for Φ (Boly et al. 2017; but see Lau 2023). For certain higher-order thought theories, having a higher-order state, supported by prefrontal cortex, without corresponding sensory states can suffice for conscious states. In this case, the front of the brain would be sufficient for consciousness. Finally, the global neuronal workspace, drawing on workspace neurons that are present across brain areas to form the workspace, might be taken to straddle the difference, depending on the type of conscious state involved. They require entry into the global workspace such that neither sensory activity nor a higher order thought on its own is sufficient, i.e., neither just the front nor the back of the brain.

The point of talking coarsely of brain anatomy in this way is to highlight the neural focus of each theory and thus, of targets of manipulation as we aim for explanatory neural correlates in terms of what is necessary and/or sufficient for generic consciousness. What is clear is that once theories make concrete predictions of brain areas involved in generic consciousness, neuroscience can test them.

4. Neuroscience of Generic Consciousness: Unconscious Vision as Case Study

Since generic consciousness is a matter of a state's being conscious or not, we can examine work on specific types of mental state that shift between being conscious or not and isolate neural substrates. Work on unconscious vision provides an informative example. In the past decades, scientists have argued for unconscious seeing and investigated its brain basis especially in *neuropsychology*, the study of subjects with brain damage. Interestingly, if there is unconscious seeing, then the intentional action inference must be restricted in scope since some intentional behaviors might be guided by unconscious perception (section 2.4). That is, the existence of unconscious perception blocks a direct inference from perceptually guided intentional behavior to perceptual consciousness. The case study of unconscious vision promises to illuminate more specific studies of generic consciousness along with having repercussions for how we attribute conscious states.

4.1 Unconscious Vision and the Two Visual Streams

Since the groundbreaking work of Leslie Ungerleider & Mortimer Mishkin (1982), scientists divide primate cortical vision into two streams: dorsal and ventral (for further dissection, see Kravitz et al. 2011). The dorsal stream projects into the parietal lobe while the ventral stream projects into the temporal lobe (see Figure 1). Controversy surrounds the functions of the streams. Ungerleider and Mishkin originally argued that the streams were functionally divided in terms of *what* and *where*: the ventral stream for categorical perception and the dorsal stream for spatial perception. David Milner and Melvyn Goodale (1995) have argued that the dorsal stream is for *action* and the ventral stream for "*perception*", namely for guiding thought, memory and complex action planning (see Goodale & Milner 2004 for an engaging overview). There continues to be debate surrounding the Milner and Goodale account (Schenk & McIntosh 2010) but it has strongly influenced philosophers of mind.

Substantial motivation for Milner and Goodale's division draws on lesion studies in humans. Lesions to the dorsal stream do not seem to affect conscious vision in that subjects are able to provide accurate reports of what they see (but see Wu 2014a). Rather, dorsal lesions can affect visual-guidance of action with *optic ataxia* being a common result. Optic ataxic subjects perform inaccurate motor actions. For example, they grope for objects, yet they can accurately report the object's features (for reviews, see Andersen et al. 2014; Pisella et al. 2009; Rossetti, Pisella, & Vighetto 2003). Lesions in the ventral stream disrupt normal conscious vision, yielding visual agnosia, an inability to see visual form or to visually categorize objects (Farah 2004).

Dorsal stream processing is said to be unconscious. If the dorsal stream is critical in the visual guidance of many motor actions such as reaching and grasping, then those actions would be guided by unconscious visual states. The visual agnosic patient DF provides critical support for this claim.[9] Due to carbon monoxide poisoning, DF suffered focal lesions largely in the ventral stream spanning the *lateral occipital complex* that is associated with processing of visual form (high resolution imaging also reveals small lesions in the parietal lobe; James et al. 2003). Like other visual agnosics with similar lesions, DF is at chance in reporting aspects of form, say the orientation of a line or the shape of objects. Nevertheless, she retains color and texture vision. Strikingly, DF can generate accurate visually guided action, say the manipulation of objects along specific parameters: putting an object through a slot or reaching for and grasping round stones in a way sensitive to their center of mass. Simultaneously, DF denies seeing the relevant features and, if asked to verbally report them, she is at chance. In this dissociation, DF's verbal reports give evidence that she does not visually experience the features to which her motor actions remain sensitive.

What is uncontroversial is that there is a division in explanatory neural correlates of visually guided behavior with the dorsal stream weighted towards the visual guidance of motor movements and the ventral stream weighted towards the visual guidance of conceptual behavior such as report and reasoning (see section 5.3 on manipulation of seeing words via ventral stream stimulation). A substantial further inference is that consciousness is segregated away from the dorsal stream to the ventral stream. How strong is this inference?

Recall the intentional action inference. In performing the slot task, DF is doing something intentionally and in a visually guided way. For control subjects performing the task, we conclude that this visually guided behavior is guided by conscious vision. Indeed, a folk-psychological assumption might be that consciousness informs mundane action (Clark 2001; for a different perspective see Wallhagen 2007). Since DF shows similar performance on the same task, why not conclude that she is also visually conscious? Presumably, one hesitates because DF's introspective reports clash with the intentional action inference. DF denies seeing features she is visually sensitive to in action. Should introspection then trump intentional action in attributing consciousness?

Two issues are worth considering. The first is that introspective reports involve a specific type of intentional action guided by the experience at issue. One type of intentional behavior is being prioritized over another in adjudicating whether a subject is conscious. What is the empirical justification for this prioritization? The second issue is that DF is possibly unique among visual agnosics. It is a substantial inference to move from DF to a general claim about the dorsal stream being unconscious in neurotypical individuals (see Mole 2009 for arguments that consciousness does not divide between the streams; see Wu 2013 for an argument for unconscious visually guided action in normal subjects). What this shows is that the methodological decisions that we make regarding how we track consciousness are substantial in theorizing about the neural bases of conscious and unconscious vision.

4.2 Blindsight

Two issues are worth considering. The first is that introspective reports involve a specific type of intentional action guided by the experience at issue. One type of intentional behavior is being prioritized over another in adjudicating whether a subject is conscious. What is the empirical justification for this prioritization? The second issue is that DF is possibly unique among visual agnosics. It is a substantial inference to move from DF to a general claim about the dorsal stream being unconscious in neurotypical individuals (see Mole 2009 for arguments that consciousness does not divide between the streams; see Wu 2013 for an argument for unconscious visually guided action in normal subjects). What this shows is that the methodological decisions that we make regarding how we track consciousness are substantial in theorizing about the neural bases of conscious and unconscious vision.[10]

The neuroanatomical basis of blindsight capacities remains unclear. Certainly, the loss of V1 deprives later cortical visual areas of a normal source of visual information. Still, there are other ways that information from the eye bypasses V1 to provide inputs to later visual areas. Alternative pathways include the superior colliculus (SC), the lateral geniculate nucleus (LGN) in the thalamus, and the pulvinar as likely sources.

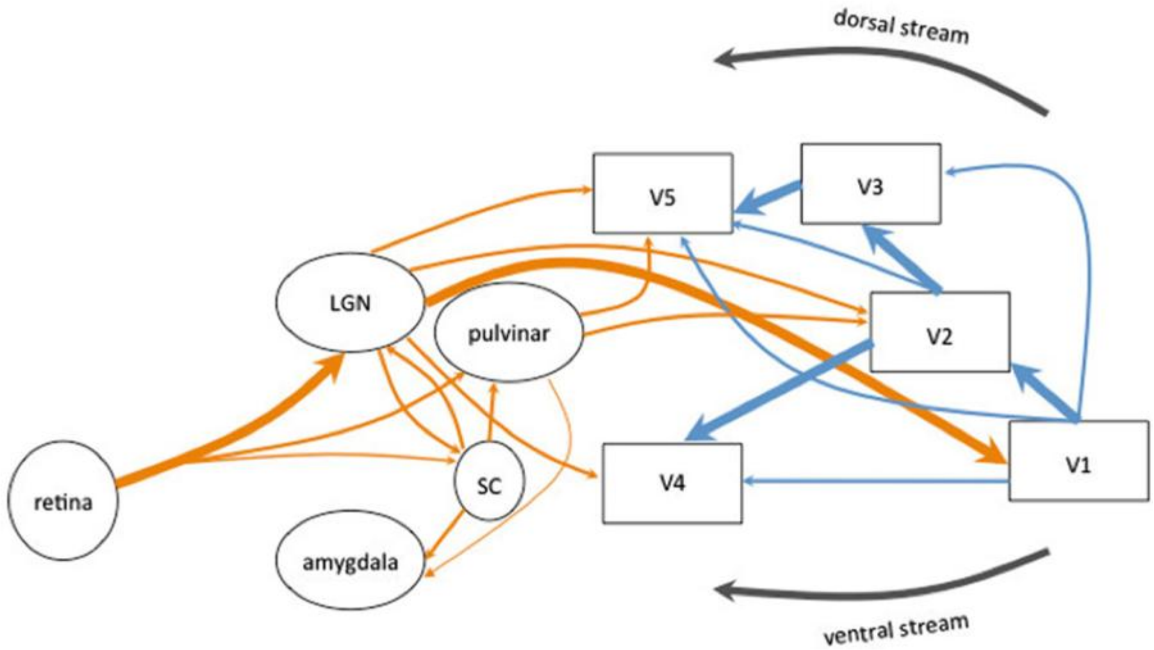

FIGURE 3. SUBCORTICAL PATHWAYS AND THEIR CONNECTION TO CORTICAL VISION (FROM URBANSKI, COUBARD, & BOURLON 2014)

Figure Legend: The front of the head is to the left, the back of the head is to the right. One should imagine that the blue-linked regions are above the orange-linked regions, cortex above subcortex. V4 is assigned to the base of the ventral stream; V5, called area MT in nonhuman primates, is assigned to the base of the dorsal stream.

The latter two have direct *extrastriate* projections (projections to visual areas in the occipital lobe outside of V1) while the superior colliculus synapses onto neurons in the LGN and pulvinar which then connect to extrastriate areas (Figure 3). Which of these provide for the basis for blindsight remains an open question though all pathways might play some role (Cowey 2010; Leopold 2012). If blindsight involves nonphenomenal, unconscious vision, then these pathways would be a substrate for it, and a functioning V1 might be necessary for normal conscious vision.

Campion et al. (1983) raised an important alternative explanation: blindsight subjects in fact have severely degraded conscious vision but merely report on them with low confidence (see Phillips 2021 for a recent version of this critique; see Michel & Lau 2021 for a response). In their reports, blindsight subjects feel like they are guessing about stimuli they can objectively discriminate. Campion et al. drew on *signal detection theory*, which emphasizes two determinants of detection behavior: *perceptual sensitivity* and *response criterion* (see section 2.1). Campion et al. hypothesized that blindsight patients are conscious in that they are aware of visual signal where discriminability is low. Further, blindsight patients are more conservative in their response so will be apt to report the absence of a signal by saying that they do not see the relevant stimulus even though the signal is there, and they can detect it, as verified by their above chance visually guided behavior.

This possibility was explicitly tested by Azzopardi and Cowey (1997) with the well-studied blindsight patient, GY. They compared blindsight performance with normal subjects at threshold vision using signal detection measures and found that with respect to motion stimuli, the difference between discrimination and detection used to argue for blindsight can be explained by changes in response criterion, as Campion et al. hypothesized. That is, GYs claim that he does not see the stimulus is due to a conservative criterion and not to a detection incapacity. Interestingly, for static stimuli, his response criterion did not change but his sensitivity did, as if he was tapping into two different visual processing mechanisms in each task (for an alternative explanation based on shifting response criterion, see Ko & Lau 2012).

In introspecting, what concepts are available to subjects will determine their sensitivity in report. In many studies with blindsight, subjects are given a binary option: do you see the stimulus or do you not see it? The concern is that the *do not see* option would cover cases of degraded consciousness that subjects might be unwilling to classify as seeing due to a conservative response criterion. So, what if subjects are given more options for report? Ramsøy and Overgaard (2004; see also Overgaard et al. 2006) provided subjects with four categories for introspective report: *no experience; brief glimpse; almost clear experience; clear experience.* Using this *perceptual awareness scale*, they found that subjects' objective performance tracked their introspective reports where performance was at chance when subjects reported no visual experience. As visibility increased, so did performance. When the scale was used with a blindsight patient (Overgaard et al. 2008), no above chance performance was detected when the subject reported no visual experience (see also Mazzi, Bagattini, & Savazzi 2016 for further evidence). A live alternative hypothesis is that blindsight does not present a case of unconscious vision, but of degraded conscious vision with a conservative response bias that affects introspection. At the very least, the issue depends on how introspection is deployed, a topic that deserves further attention (see Phillips 2016, 2021 for further discussion of blindsight).

4.3 Unconscious Vision and the Intentional Action Inference

Blindsight and DF show that damage to specific regions of the brain disrupts normal visual processing, yet subjects can access visual information in preserved visual circuits to inform behavior despite failing to report on the relevant visual contents. The received view is that these subjects demonstrate unconscious vision. One implication is that the normal processing in the ventral stream, tied to normal V1 activity, plays a necessary role in normal conscious vision. Another is that dorsal stream processing or visual stream processing that bypasses V1 via subcortical processing yields only unconscious visual states. This points to a set of networks that begin to provide an answer to what makes visual states conscious or not. An important further step will be to integrate these results with the general theories noted earlier (section 3).

Still, the complexities of the empirical data bring us back to methodological issues about tracking consciousness and the following question: What behavioral data should form the basis of attributions of phenomenal consciousness? The intentional action inference is used in a variety of cases to attribute conscious states, yet the results of the previous sections counsel us to be wary of applying that inference widely. After all, some intentional behavior might be unconsciously guided.

In the case of DF, we noted that unlike many other visual agnosics, she can direct motor actions towards stimuli that she cannot explicitly report and which she denies seeing. In her case, we prioritize introspective reports over intentional action as evidence for unconscious vision. Yet, one might take a broader view that vision for action is always conscious and that what DF vividly illustrates is that some visual contents (dorsal stream) are tied directly to performance of intentional motor behavior and are not directly available to conceptual capacities deployed in report. In contrast, other aspects of conscious vision, supported by the ventral stream, are directly available to guide reports. This functional divergence is explained by the anatomical division in cortical visual processing.

For some time now, these striking cases have been taken as clear cases of unconscious vision and if this hypothesis is correct, the work has begun to identify visual areas critical for creating seeing, sometimes conscious and sometimes not. The neuroanatomy demonstrates that visually-guided behavior has a complex neural basis involving cortical and subcortical structures that demonstrate a substantial level of specialization. Understanding consciousness and unconsciousness in vision will need to be sensitive to the complexities of the underlying neural substrate.

5. Specific Consciousness

We turn to experimental work on specific consciousness:

Specific Consciousness: What neural states or properties are necessary and/or sufficient for a conscious perceptual state to have content *X* rather than *Y*?

In this section, we examine attempts to address claims about necessity and sufficiency by manipulation of the contents of consciousness through direct modulation of neural representational content.

5.1 Neural Representationalism

In thinking about neural explanations of specific consciousness, namely the contents of consciousness, we will provisionally assume a type of first-order representationalism about phenomenal content, namely that such content supervenes on neural content (see the entry on representational theories of consciousness). One strong position would be that phenomenal content is *identical* to appropriate neural content. A weaker correlation claim affirms only supervenience: no change in phenomenal content without a change in neural content. This neural representationalism allows us to link phenomenal properties to the brain via linking neural contents to perceptual contents.

In invoking neural content, the assumption is that neural content mirrors perceptual content, so that if one is experiencing dots moving in a certain direction, there is a neural representation with the same content. This is a simplification and does not cohere with a common current approach to neural content that takes it to be *probabilistic* (for accessible discussions, see Pouget, Dayan, & Zemel 2003; Colombo & Seriès 2012; Rescorla 2015). Yet perceptual content does not *seem* probabilistic. This emphasizes a *prima facie* disconnect between current theories of neural content and those of phenomenal content. One option is to find nonprobabilistic content at the neural level. The other is to find probabilistic content at the phenomenal level (for related ideas, see Morrison 2016 and a response by; Denison 2017; and Beck 2020; also Munton 2016; Block 2018; Shea 2018; Gross 2020; Vance 2021; Siegel 2022; Lee & Orlandi 2022). For simplicity, in what follows we assume a simple mapping between neural content and perceptual experiences.

5.2 The Contrast Strategy: Binocular Rivalry

A common approach, the *contrast strategy*, enjoins experimentalists to identify relevant correlates for some phenomenon *P* by contrasting cases where *P* is present from cases where *P* is not. Work on binocular rivalry illustrates this strategy (among many reviews, see Tong, Meng, & Blake 2006; Blake, Brascamp, & Heeger 2014; Blake 2022). When each eye receives a different image simultaneously, the subject does not see both, say one stimulus overlapping the other. Rather, visual experience alternates between them. Call this *phenomenal alternation*. An initial restatement of our question about specific consciousness in respect of binocular rivalry is:

Specific Rivalry: What neural property is necessary and/or sufficient for phenomenal alternation in binocular rivalry in condition *C*?

That is, empirical theories aim to explain how visual content alternates in binocular rivalry.[11] Notice that this is a question about specific rather than generic consciousness, as the contrast is not between a state's being conscious versus not but about the contrast between two conscious states with different contents

Neural explanations of binocular rivalry concern competition at some level of visual processing: (a) "interocular" competition between *monocular* neurons early in the visual system, namely visual neurons that receive input from only one eye or (b) competition between *binocular* neurons later in the visual system, namely neurons that receive input from both eyes. The winner of competition fixes which stimulus the subject experiences at a given time. Some imaging studies in humans suggest that neural activity in V1 did correlate with alternation of the experienced images. For example, Polonsky et al. used fMRI to demonstrate that V1 activity to competing stimuli tracked perception (Polonsky et al. 2000; but see Maier et al. 2008). In contrast, some of the earliest electrophysiological studies (Leopold & Logothetis 1996; Logothetis, Leopold, & Sheinberg 1996; see also Hesse & Tsao 2020) on awake behaving monkeys supported later binocular processing as the neural basis of binocular rivalry. Processing in later (inferotemporal cortex, IT; see Figure 1) rather than earlier visual areas (V1 or V2) was observed to be best correlated to the monkey's reported perception based on the monkey's stimuli-specific response.

Recent accounts have taken binocular rivalry as resulting from processes at multiple levels (Wilson 2003; Freeman 2005; Tong, Meng, & Blake 2006). For example, when the two competing stimuli have parts that can be fused into a coherent stimulus, as when half of a picture is presented to each eye, the subject can perceive the fusion, integrating content from each eye (Kovács et al. 1996; Ngo et al. 2000). This suggests that binocular rivalry can be sensitive to global properties of the stimulus (see Baker & Graf 2009). What unifies the mechanisms, perhaps, is the function of resolving a conflict generated by the stimuli.

Assume that some neural process *R* resolves interocular competition: when *R* resolves competition between stimuli *X* and *Y* in favor of *X*, then the subject is phenomenally conscious of *X* rather than *Y* and vice versa. Notice that *R* has the same "gating" function for any stimuli *X* and *Y* that are subject to binocular rivalry. So, while the presence of *R* can explain why the subject is having one conscious visual experience rather than another, *R* is not tied to a specific content. This suggests that in answering the question about rivalry, we will at best be identifying a necessary but not sufficient condition for a conscious visual state having a content *X*. *R* is a general gate for consciousness (cf. attention in global workspace theory).

An example of this gating of awareness can be found in recent studies using no-report paradigms, in which analysis of local field potentials in macaque prefrontal cortex has shown that transitions in frequency field activity track transitions in experience and encoding of the contents of conscious experiences (Dwarakanath et al. 2023). Moreover, feature-selective neurons in the prefrontal cortex are modulated by subjective changes in experiences (regardless if these were due to physical changes or rivalry). This modulation allows trial-by-trial successful decoding of the contents of experience from prefrontal cortex (Kapoor et al. 2022). Together, these recent studies offer robust evidence for a causal role of prefrontal cortex in supporting conscious experiences.

A narrower explanation of specific consciousness would identify the specific neural representations that explain a conscious state's having the specific content *X* (rather than *Y*). By the representationalism assumption, this will involve identifying neural representations with the same content, *X*. Focusing on a gate in explaining alternation in rivalry stops short of identifying those representations. Still, binocular rivalry can provide a useful method for isolating neural populations that carry relevant content. In principle, for any stimulus type of interest, *X* (e.g., faces, words, etc.), so long as *X* is subject to binocular rivalry, we can use rivalry paradigms to isolate brain areas that carry the relevant information that correlate with the subject's perceiving *X*. That would allow us to identify potential candidates for the neural basis of conscious content. (For a criticism of binocular rivalry paradigms as a means for discovering the neural basis of perceptual awareness—as opposed to mere perceptual processing—see Zou, He, & Zhang 2016; Giles, Lau, & Odegaard 2016).

5.3 Neural Stimulation

There are limited opportunities to manipulate human brain activity in a targeted way. Recent use of transcranial magnetic stimulation to activate or suppress neural activity has provided illumination, but such interventions are coarse-grained. Ultimately, to locate an explanatory correlate for specific conscious contents, we will need more fine-grained interventions in brain tissue. In humans, such opportunities are generally confined to manipulation before surgical interventions, say for brain tumors or epilepsy.

In the middle of the last century, neurosurgeon Wilder Penfield and colleagues performed a set of direct electrical microstimulations during preoperative procedures (Penfield & Perot 1963), and in certain cases induced hallucinations by stimulating primary sensory cortices such as V1 or S1 (see Figure 1). This provided evidence that endogenous activity could be causally sufficient for phenomenal experiences. Penfield's interventions, however, were not based on fine-grained targeting of specific neural representations. As Cohen and Newsome note:

Penfield's approach failed to generate substantial new insights into the neural basis of perception and cognition…because the gross electrical activation elicited by surface electrodes could not be related mechanistically to the information being processed within the excited neural tissue. (Cohen & Newsome 2004: 1)

A different approach begins with a more detailed understanding of underlying neural representations tied to different brain regions (Figure 4). For example, the fusiform face (FFA) area appears to be necessary for normal human face experience in that lesions in FFA lead to *prosopagnosia*, the inability to see faces even if one can see their parts [whether FFA is necessary for seeing faces specifically, or more generally for visual expertise is a point of contention (Kanwisher 2000; Tarr & Gauthier 2000)]. FFA is part of a larger network that is important in visual processing of faces (Behrmann & Plaut 2013). Recently, microstimulation of FFA in an awake human epilepsy patient induced visual distortions of actual faces as opposed to other objects (Parvizi et al. 2012). Alterations of visual experience were also reported during microstimulating the parahippocampal place (PPA) area in an awake pre-operative epileptic patient that induced visual hallucinations of scenes (Mégevand et al. 2014). PPA is the same area that showed activation in patients with unresponsive wakefulness syndrome when they putatively imagined walking around their home (section 2.4).

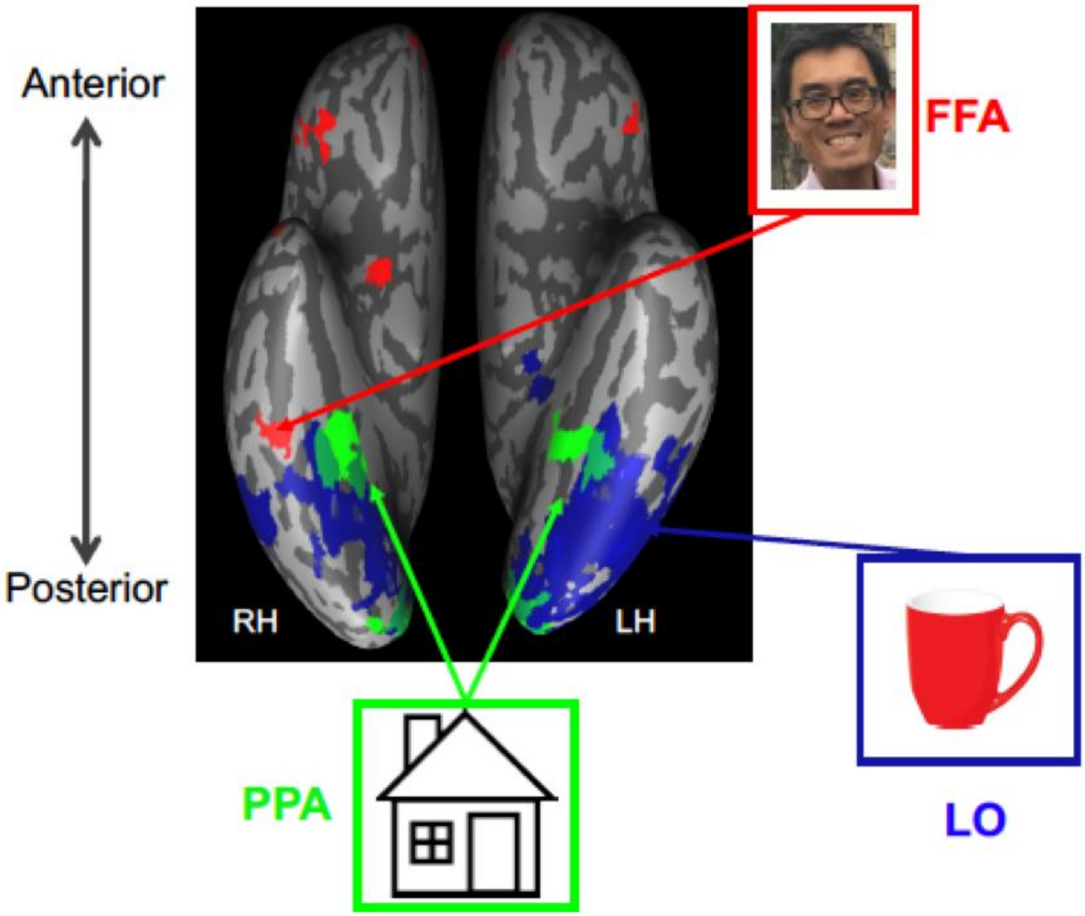

FIGURE 4. VENTRAL STREAM AREAS

A view from the bottom of cortex with location of areas FFA, PPA and LO identified. Occipital cortex is on the bottom. LO is lesioned in the visual agnosic patient, DF (see section 4.1). This figure is modified from figure 1 of Behrmann and Plaut 2013, kindly provided by Marlene Behrmann and used with her permission.

Another successful example of target microstimulation involves the visual word form area. This region in the left midfusiform gyrus (lmFG) is important for normal processing of visual word forms during reading. Microstimulation in human epileptic patients selectively disrupted word and letter reading—presumably altering the visual experience of letters—without changing general form perception (Hirshorn et al. 2016) (see Movies S1 and S2 in Other Internet Resources).

It is worth noting that many neuroscientists of vision take themselves to be investigating seeing in the ordinary sense, one that implies consciousness, but very few of them would characterize their work as about consciousness. That said, their work is of direct relevance to our understanding of specific consciousness even if it is not always characterized as such.[12]

An important approach in visual neuroscience was articulated by A.J. Parker and William Newsome in "Sense and the Single Neuron" (1998) via "principles" to connect electrophysiological data about information processing to perception (for a recent discussion, see Ruff & Cohen 2014). To probe the neural basis of perception, neuroscientists need to explanatorily link neural data to the subject's perception that guides behavior. The experimenter must ensure that recorded neural content correlates with perceptual content and not just response. Further, manipulation of the neurons carrying information should affect perception: inducing appropriate neural activity should shift perceptual response while abolishing or reducing that activity should eliminate or reduce perceptual response as measured in behavior. These proposals address concerns about necessity and sufficiency.

The intentional action inference is applicable (or at least its evidential version):

If some subject acts intentionally, where her action is guided by a perceptual state, then that state is phenomenally conscious.

We will consider the strength of this inference in two cases. The first case, visual motion perception, introduces the principles that guide the manipulation of neural content while the second case concerns tactile experience of vibration. These cases involve experiments with non-human primates, so we lack introspective reports. But direct manipulation of the human brain along with introspective reports have been performed too as discussed above with respect to face and letter perception.

These experiments involve microstimulation of small populations of neurons that are targeted precisely because of their informational content. Microstimulation involves injecting a small current from the tip of an electrode inserted into brain tissue that directly stimulates nearby neurons or, through synaptic connections to other neurons, indirectly activates more distant neurons (see Histed, Ni, & Maunsell 2013 for a review). It is assumed that neurons *tuned* in similar ways, that is neurons that respond to similar stimuli, tend to be interconnected, so microstimulation is taken to largely drive similarly tuned neurons.

5.3.1 Visual Motion Perception

We begin with visual motion perception in primates. Since the principles introduced here are central to much perceptual neuroscience and provide the basis for probing the link between neural representations and perceptual content, I examine it carefully. The salient question will be whether conscious experience is changed by the manipulations.

The work we shall discuss was done in awake behaving macaque monkeys. Visual area MT in the monkey brain (called V5 in humans) plays an important role in the visual experience of motion. MT is taken to lie in the dorsal visual stream (Figure 1). Lesions that disrupt MT are known to cause *akinetopsia*, the inability to see motion. One patient with an MT (V5) lesion reported the following phenomenology: "people were suddenly here or there but I have not seen them moving" (Zihl, von Cramon, & Mai 1983: 315). MT processing looks to be necessary for normal visual motion experience. Furthermore, MT neurons represent (carry information regarding) the direction of motion of visible stimuli: MT neurons are *tuned* for motion in specific directions with the highest firing rate for a specific direction of motion (for other functions and responses of MT, see Born & Bradley 2005). By placing motion stimuli in a neuron's receptive field, scientists can map its tuning:

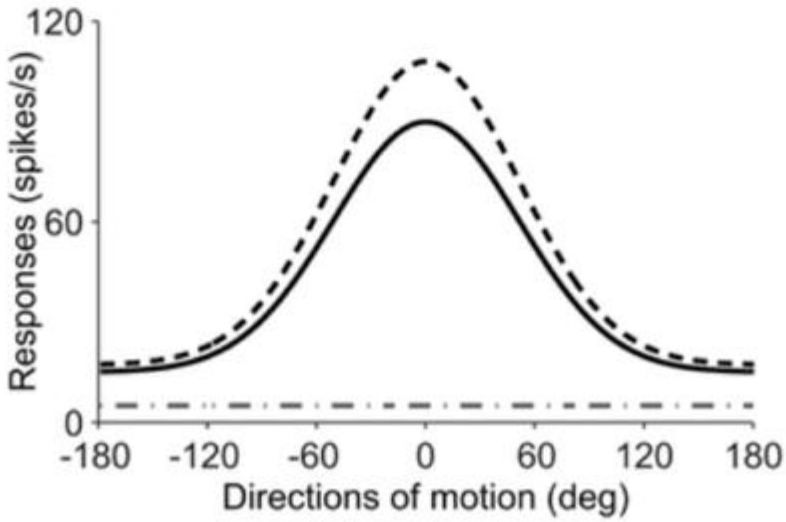

FIGURE 5. MT Neuron Tuning Curve

Figure Legend: Tuning of a neuron in MT showing a peak response in spiking rate at 0 degrees of motion. The dashed curve is generated when the animal is attending to the motion stimulus while it is in the receptive field (we shall not discuss the neural basis of attention, but see Wu 2014b: chap. 2 for a summary of the neuroscience of attention). The solid curve shows MT response when the animal is not attending to the motion stimulus in the receptive field. Figure from (Lee & Maunsell 2009).

What is plotted is the activity of an MT neuron, in spikes per second, to a specific type of motion stimulus placed within its receptive field. How to relate a tuning curve to a determinate content is complicated. Since the neural response is not simply to one stimulus value, it is not obvious that the neuron should be taken to represent 0 degrees of motion, namely the value at its peak response. Indeed, theorists have noted that the tuning curve looks like a probability density function, and many now take neurons to have *probabilistic* content (section 5.1).

Experimenters have trained macaque monkeys to perform discrimination tasks reporting direction of motion. Typically, the monkey maintains fixation while the moving stimulus is placed within the receptive field of the recorded neuron. The monkey reports the direction of the stimulus by moving its eyes to a target that stands for either leftward or rightward motion (other behavioral reports can be generated such as moving a joystick). Provisionally, we apply the intentional action inference, so we assume that such reports are guided by conscious visual experience of the stimuli. Thus, *changes in behavior will be evidence for changes in conscious content.*

Early work suggested that the activity of a single neuron provides a strong correlate of the animal's visually guided performance. This can be seen by plotting both the animal and the neuron's performance across different stimulus values. In these experiments, the value concerns the percent *coherence* of motion of a set of dots defined as the number of dots moving in the same direction (0% coherence being random motion; 100% being all dots moving in the same direction). In the first case, we construct a *psychometric curve* that plots the animal's percent correct reports relative to percent coherence of motion of the stimuli. As one might expect, percent correct reports drop as coherence drops, and the inflection point reflects where the subject is equally likely to indicate left or right motion. We can do the same for the neural activity of the neuron across the same stimulus values, a *neurometric curve*.

The experimentalist's window onto conscious experience is through behavior, the assumption being that report about motion correlates with perceptual experience. Correlation is assessed by asking the following question: would an ideal observer, using the activity of the neuron in question, be able to *predict* the animal's visually guided performance? Essentially, do the psychometric and neurometric curves overlap? Strikingly, yes. MT neurons were observed to predict the animal's behavior (Britten et al. 1992).

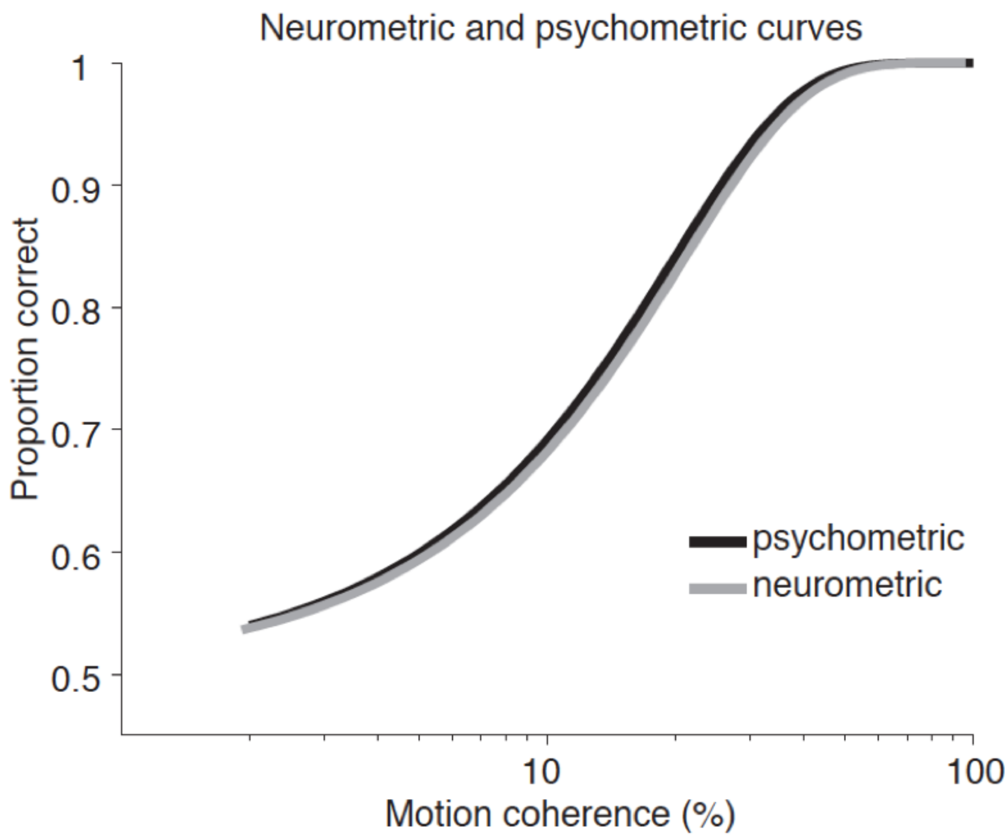

FIGURE 6. PSYCHOMETRIC AND NEUROMETRIC CURVES

Figure Legend: Psychometric and neurometric curves for a single MT neuron during performance of a motion direction detection task. Percent correct performance is plotted on the y-axis while percent motion coherence is plotted in a log scale on the x-axis. Figure modified from Ruff & Cohen 2014 and kindly provided by Doug Ruff.

This shows that the activity of a single MT neuron provides a neural correlate of the animal's visual discrimination of motion. Note that this is just a neural correlate of behavior. No one suggested that this neuron was causally sufficient for the behavior or for perception. Later results have suggested that individual neurons are not quite as sensitive as Britten suggested, but that small groups of MT neurons are sufficient to predict behavior (Cohen & Newsome 2009).

Earlier, we worried about mere correlates. To get causal or explanatory purchase, the content of the MT neurons correlated to the animal's behavior must be shown to contribute to perceptual guidance. This predicts that if we manipulate the content of the neurons, i.e., manipulate neural representations, then we should manipulate the content of the animal's visual experience of motion as reflected by predicted changes in behavior. This would be to test sufficiency with respect to specific consciousness.

Newsome and colleagues demonstrated that microstimulation of MT neurons shifted the animal's performance in predictable ways. Assume that neural population *P*, by encoding information about stimulus motion, can inform the subject's report of motion direction. This information is accessible for the control of behavior. Activation of *P* by microstimulation should shift behavior in a motion selective way correlated with the direction that *P* is tuned to (represents). This was first demonstrated by Salzman et al. (1990). They inserted electrodes into MT and identified neurons tuned to a particular orientation. During a motion discrimination task, microstimulation of neurons with that tuning led to a shift in the psychometric curve as if that neuron was given more weight in driving behavior.

In conditions of microstimulation relative to its absence, the monkey was more likely to report that there was motion in the stimulated neuron's preferred direction. In the original experiment, the psychophysical effect of microstimulation was equivalent to the addition of 7–20% coherence in the stimulus with respect to the neuron's preferred direction, depending on the experimental conditions. Further, as a test of necessity, a selective lesion of MT disrupted motion discrimination though the animals were able to recover some function suggesting that other visual information streams could be tapped so as to support performance (Newsome & Paré 1988).

Adopting the intentional action inference, one can conclude that the microstimulation shifted perceptual content (or again, that we have good evidence for this shift). That said, given our discussion of unconscious vision (section 4), another possibility is that MT microstimulation only changes unconscious visual representations. Newsome himself asked:

What is the conscious experience that accompanies the stimulation and the monkey's decision? Even if you knew everything about how the neurons encode and transmit information, you may not know what the monkey experiences when we stimulate his MT. (Singer 2006)

Clearly, having the monkey provide an introspective report would add evidential weight, but obtaining such reports from non-linguistic creatures is difficult. How can we get the animal to turn attention *inward* to their perceptual states in an experimental context?[13]

5.3.2 Tactile Vibration

What of microstimulation in the absence of a stimulus? Might we induce *hallucinations* as Penfield did in his patients? Rather than modulation of ongoing perceptual processing, the issue here is to create an internal signal that mimics perception. Romo et al. (1998) demonstrated that monkeys can carry out sensory tasks via activation triggered by microstimulation. The monkeys' task was to discriminate the frequency of two sequential "flutters" on their fingertips, that is, mechanical vibrations on the skin at specific frequencies.

In an experimental trial, an initial *sample* flutter was presented for 500 ms and after a gap of 1–3 seconds, a second *test* flutter of either higher or lower frequency was presented. The animal reported whether the second test frequency was higher or lower than the sample.

The experimenters examined whether direct microstimulation in the absence of a stimulus could tap into the same neural representations that guided the animal's report. They isolated neurons in primary somatosensory cortex responsive to vibration frequency on the fingers (S1, the somatosensory homunculus discovered by Penfield & Boldrey [1937]; see Figure 1). The investigators then stimulated the same neurons in S1 in the absence of the test flutter, so used stimulation as a substitute for an actual vibration. Thus, the animal had to make a comparison between the frequency of a mechanical sample to either a subsequent (1) real mechanical test vibration (i.e., the good case with an actual stimulus) or (2) to a microstimulation test stimulus (i.e., the "hallucinatory" case where direct activation of the S1 neurons occurred in the absence of a stimulus). Romo et al. demonstrated that discrimination performance based either on mechanical stimulation or microstimulation was *equivalent*. In other words, the animals could match either mechanical or microstimulation to a remembered mechanical sample.[14] (For a related approach with visual stimuli and optogenetic stimulation, see Azadi et al. 2023)

In subsequent work (Romo et al. 2000), the investigators inverted the experiment, using the microstimulation as the *sample*. In this case, the animals had to remember the information conveyed by the microstimulation (effectively, a hallucination) and then compare it to either a subsequent (a) mechanically generated stimulation on the finger (actual test stimulus) or (b) a microstimulation of S1 as test (i.e., no stimulus). In both cases, performance was similar to earlier results. The striking finding is that behavior could be driven entirely by microstimulation. At least for the tactile stimulations at issue, the animal might have been in the *Matrix*!

One might think that the intentional action inference is stronger in this paradigm, given the elegant flipping of stimuli in Romo et al. 2000. Still, the authors comment:

This study, therefore, has directly established a strong link between neural activity and perception. However, we do not know yet whether microstimulation of the QA circuit in S1 elicits a subjective flutter sensation in the fingertips. This can only be explored by microstimulating S1 in an attending human observer. (Romo et al. 2000: 277)[15]

Like Newsome, the authors reach for introspection. Yet they might undersell their result, for it seems that the animals are having a tactile hallucination: (a) Penfield showed that stimulation of primary sensory cortices like S1 induces hallucinations in humans; (b) action is engaged not at low stimulation of S1 in monkeys but only at higher level stimulation; (c) at that point, when the stimulation grabs their attention, the monkeys do what they were trained to do, namely discriminate stimuli, either with (d) just mechanical stimulation (normal experience), or (e) with a mix of mechanical and microstimulation or with just microstimulation; (f) given the behavioral equivalence of these three cases, one might then argue that if performance in the mechanical stimulation cases involves conscious tactile experience, then that same experience is involved in the other cases.

Taken together, these cases provide examples of detailed manipulations in different sensory modalities, animals, and contents that test for causal sufficiency and necessity across different levels of the sensory processing hierarchy, from early levels (e.g., S1) to mid-levels (MT) and, as discussed at the outset of this section, to higher levels (lmFG or FFA). One issue that remains open is whether in tapping into neural processing by microstimulation, one has simply identified an earlier causal node in the neural processes that generate perceptual experience, there being more informative neural correlates later in the causal pathway.

6. The Future

Talk of the neuroscience of consciousness has, thus far, focused on the neural correlates of consciousness. Not all neural correlates are explanatory, so finding correlates is a first step in the neuroscience of consciousness. The next step involves manipulation of relevant correlates to test claims about sufficiency and necessity, as isolated in our two questions:

Generic Consciousness: What conditions/states *N* of nervous systems are necessary and (or) sufficient for a mental state, *M*, to be conscious as opposed to not?

Specific Consciousness: What neural states or properties are necessary and/or sufficient for a conscious perceptual state to have content *X* rather than *Y*?

A productive neuroscience of consciousness requires that we understand the relevant neural properties at the right level of analysis. For generic consciousness, this will involve manipulation of relevant properties in a way that can avoid the access/phenomenal confound, and recent work focuses on pitting the many theories we have considered against each other. For specific consciousness, the critical issue will be to understand neural representational content and to find ways to link experimentally and explanatorily neural content to phenomenal content. We have tools to manipulate neural contents to affect phenomenal content, and in doing so, we can begin to uncover the neural basis of conscious contents. There is much interesting work yet to be done, philosophically and empirically, and we can look forward to a productive interdisciplinary research program.

The Staggering Complexity of the Human Brain

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

Posted September 2, 2023 | Reviewed by Ray Parker

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

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

Source: theartofsounds2001 | Pixabay

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

Staggering Numbers

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

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

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

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

Is it really the most complex thing?

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

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

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

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

Mapping the Brain

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

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

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

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

Remaining Mysteries

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

In ancient Egypt, for example, the brain was discarded during the mummification process, while the heart was carefully preserved (see Ancient Concepts of the Mind, Brain (and Soul), Pang, 2023a). We now know that the brain is linked to our thoughts, emotions, and experiences.

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

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

Conclusion

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

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Apple is reportedly asking Sony for help with its Vision Pro problem

The Apple Vision Pro seems to be a disappointment for CEO Tim Cook. Will a Sony handset deal help change that? ANGELA WEISS/AFP via Getty Images© ANGELA WEISS/AFP via Getty Images

- Apple's Vision Pro headsets went on sale in February. They have not taken the world by storm.
- Apple is reportedly looking to Sony for help via a plan to bring Sony's gaming controllers to Apple's devices.
- But unlike other headsets, the Vision Pro isn't really built for gaming. So, this seems unlikely to solve Apple's long-term Vision Pro problem.

Maybe, one day, the Apple Vision Pro — or a future version of the Apple Vision Pro — will end up being a huge hit for Apple.

Right now, it seems anything but.

As we've noted multiple times, there are several indicators that Apple's "mixed reality" goggles aren't a breakthrough product. Most important: There doesn't seem to be a killer app that creates a use case for the Vision Pro, which starts at $3,500.

Apple has always positioned the device, which launched in February, as the first step for "spatial computing" — not the end state. Still, it's hard to imagine it didn't have higher hopes for the initial product.

Now Bloomberg's Mark Gurman reports that both sales and usage are underwhelming. He says Apple has sold fewer than 500,000 units of the device, and that "a large number of Vision Pro buyers (those who haven't returned it) aren't using the product as much as Apple anticipated, according to internal data gathered by the company."

What could change all of that? Perhaps a cheaper, lighter version, which could hit the market next year. But Apple is also reportedly looking outside the company for help, by integrating third-party controllers for the device.

Gurman reports that Apple is working with Sony on a deal that will let Vision Pro owners use a version of the PlayStation VR2's hand controllers with the device. That's a notable change since, right now, the Vision Pro doesn't use any controllers at all. Instead, users manipulate the gadget using their fingers and eyes.

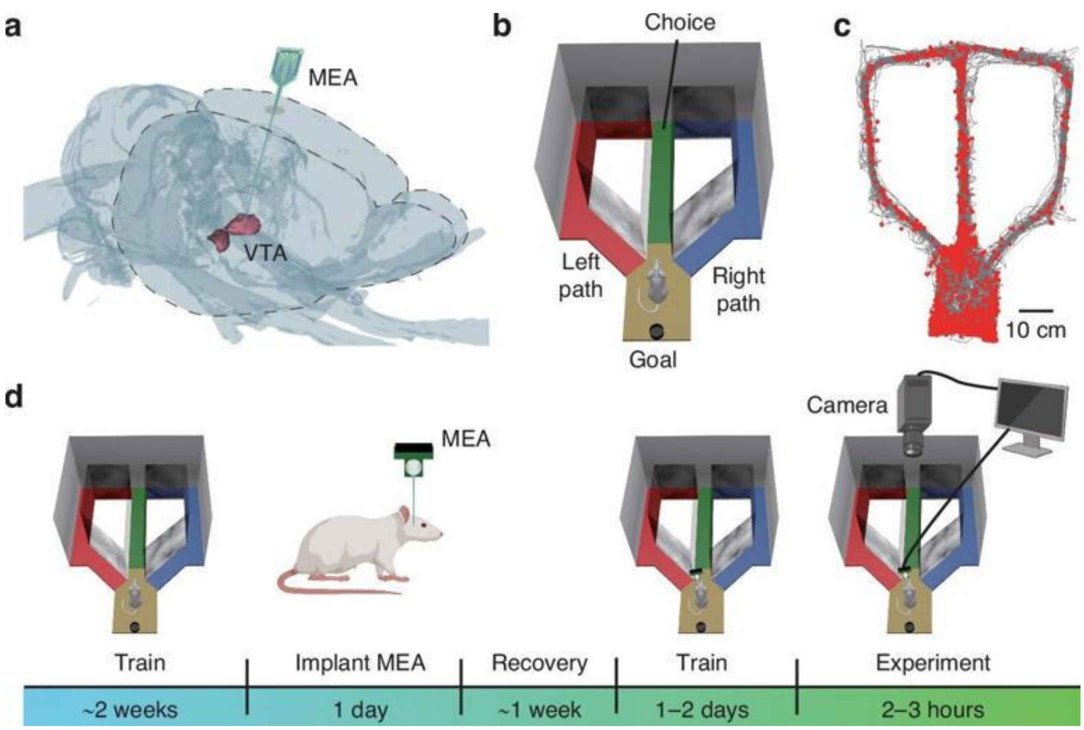
That's a pretty cool and novel way to use a computer (again, I really urge anyone who hasn't tried Vision Pro to book a free, 30-minute demo at an Apple store). But that choice also means that developers who built something for other augmented/virtual/mixed reality devices — which generally *do* use hand-held controllers — would have a hard time porting their applications to Apple's new device.

Which makes the killer app problem that much harder to solve.

But even if the Apple-Sony deal does happen soon (I've asked both companies for comment) I don't think it immediately changes the Vision Pro's prospects.

Apple headset rivals like Sony and Meta are positioning their devices as gaming consoles (Meta is bundling a Batman game with its newest Quest headsets). But the Vision Pro just seems too expensive and bulky to support video games at scale. This move seems more like an indicator that Apple knows it has a problem. It's not a solution.

Low-curvature microelectrode arrays record spatial cognitive information coding in the deep brain



Electrophysiological recording and behavioral tasks. Credit: Microsystems & Nanoengineering (2024). DOI: 10.1038/s41378-024-00778-2

A research group led by Prof. Cai Xinxia from the Aerospace Information

Research Institute (AIR) of the Chinese Academy of Sciences developed a new method for fabricating high-precision, low-curvature microelectrode arrays (MEAs), which are designed for recording neuronal activities in the brain's deep small volume region. The study was published in *Microsystems & Nanoengineering*.

Animals have a natural navigation system that directs them to destinations crucial for their survival. John O'Keefe, along with the couple May-Britt Moser and Edvard Moser who won the Nobel Prize in Physiology or Medicine in 2014, has used microfilament electrodes to discover special cells in the brain—place cells and grid cells—located in the hippocampus and entorhinal cortex which help with spatial navigation. Accurately implanting electrodes in the deeper brain regions such as the ventral tegmental area (VTA) has been challenging.

In this study, researchers introduced an innovative backside dry etching method to release residual stress of MEAs, allowing for precise control of electrode bend direction from positive to negative. They can create low-curvature MEAs by precisely adjusting certain parameters.

To confirm the effectiveness of this method, researchers used simulation and histological methods, and found significant improvement in stress distribution and implantation accuracy of the low-curvature MEAs. This method shows a better performance in terms of curvature than the advanced neural probe Neuropixels.

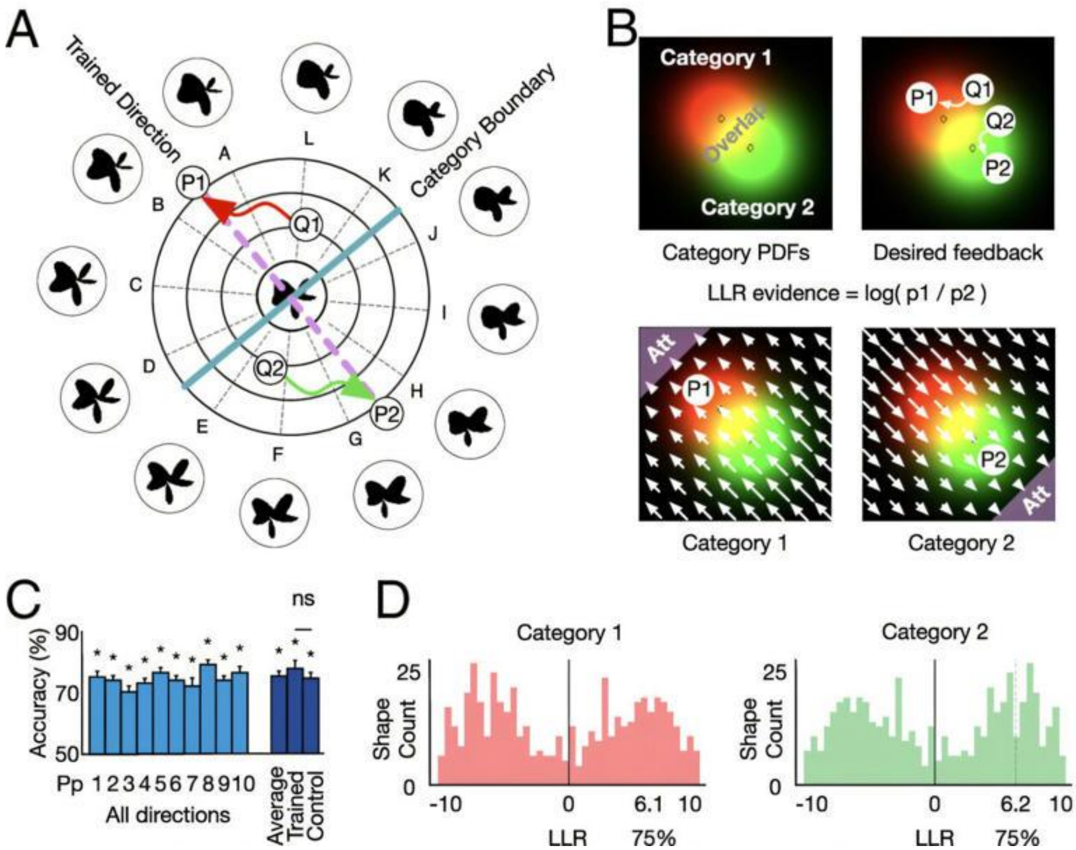
In the goal-directed navigation task, researchers implanted the low-curvature MEAs into the VTA of rats, and recorded the movement trajectory of rats alongside the electrophysiological activity of VTA neurons. By analyzing both time and position data, they found specific discharge patterns and adaptive changes in the VTA neurons regarding rewards and spatial information. Notably, the disappearance and reconstruction of the place fields were linked to shifts in the relationship between path taken and outcomes achieved.

The study develops low-curvature MEAs with improved temporal and spatial resolution, which enhances implantation accuracy and signal quality for deep brain neuron information detection. It also provides insights into the role of VTA in goal-directed navigation.

More information: Wei Xu et al, Neuronal activity in the ventral tegmental area during goal-directed navigation recorded by low-curvature microelectrode arrays, *Microsystems & Nanoengineering* (2024). DOI: 10.1038/s41378-024-00778-2

Provided by Chinese Academy of Sciences

Scientists develop new approach to learning through noninvasive manipulation of brain activity patterns



Using a neural model of the shape space to guide neurofeedback. Credit: Proceedings of the National Academy of Sciences (2024). DOI: 10.1073/pnas.2410445121

Imagine being able to inscribe a new pattern of activity into a person's brain that would allow for faster learning, or better treatment of psychiatric and developmental disorders such as depression or autism. Now imagine being able to do that in a way that doesn't require brain surgery or any physical manipulation. Sounds like science fiction?

It still is. But that's exactly what Coraline Iordan, an assistant professor of brain and cognitive sciences and of neuroscience at the University of Rochester has been working toward, showing for the first time that it can certainly be done for learning new visual categories of objects.

Generally, learning happens when our brain changes through experience, study, or instruction. But Iordan and colleagues at Yale and Princeton successfully tested a novel approach for teaching the human brain to learn through external manipulation and neural feedback—what they call the "sculpting" of brain activity patterns. The research is published in the *Proceedings of the National Academy of Sciences*.

"With our method not only can we nudge complex patterns around in the brain toward known ones, but also—for the first time—write directly a new pattern into the brain and measure what effect that has on a person's behavior," says lead author Iordan.

Brain sculpting—a new approach to learning?

The scientists used real-time neuroimaging and second-by-second neurofeedback to modify how the brain represents and processes information about visual objects. Lying inside a functional magnetic resonance imaging (fMRI) machine, study participants viewed objects projected onto a mirror above their heads, which looked like a small screen.

The object—an abstract shape that some participants described as a petal, plant bulb, or butterfly—pulsed gently on the participants' mirror until they managed to "move it" by aligning their own thought processes to the pattern of activity in their brain (monitored via fMRI in real time) that the scientists had previously chosen. The researchers instructed the participants to "generate a mental state" that would reduce the shape's oscillation but had not taught the study participants how to achieve such mental state.

"One of the striking features of the study is that the neural responses and corresponding behavior to the new categories occurred without explicit awareness of those categories, showing that a long tradition of work in psychology on implicit processing—that is, the ability to respond to information meaningfully outside of awareness—also extends to the learning and formation of new neural representations," says co-author Jonathan Cohen, a cognitive neuroscientist at Princeton University.

The immediate feedback given to the study participants here meant that the image stopped wobbling on their mirror once they successfully managed to represent the visual object more similarly to a brain activity pattern that the researchers had previously designated, instead of how the object would have been represented in their brains naturally.

In other words, the scientists had developed a method that caused people to learn new categories of visual objects, not by teaching them what the categories were, but by changing how their brains worked when they looked at the individual objects in those categories.

"Instead of teaching you something and measuring how your brain changes, we wrote a new category into your brain that would have appeared had you learned it yourself," explains Iordan. "Then we tested whether you saw the new category that we had inserted. Turns out you did."

To ensure study participants were highly motivated to succeed, they were rewarded monetarily if they managed to stop the image wobble, which over six daily sessions could amount to a sizable bonus.

Future applications

Scientists are working to better understand what exactly happens to brain function in people with a variety of neuropsychiatric, developmental, or psychological disorders, such as major depression, visual agnosias (the inability to recognize everyday items), and autism.

According to Iordan, a method like theirs may eventually play a role in clinical treatment by modifying the brain patterns of patients to make theirs look more similar to the brain patterns found in the neurotypical population, which down the road could lead to new approaches for treatment, either by itself or in conjunction with already existing therapies.

"This study is one of the most powerful demonstrations yet of brain training with real-time fMRI. Dr. Iordan used neurofeedback to help humans create a category in their mind that then influenced their behavior," says co-author Nicholas Turk-Browne, a psychologist at Yale University. "In the future, this discovery could inform the development of brain-computer interfaces and clinical interventions."

At its core lies the scientists' ability to access the brain in a way that hasn't been done before.

"We essentially turned learning on its head and taught your brain something that caused you to vicariously gain information, even though you were never explicitly given that information," says Iordan. "That tells us we have access to the building blocks of learning in the brain in a way that we haven't had before—for learning things that are much more complicated, such as entire categories of items, complex visual things, or potentially even beyond that someday."

More information: Coraline Rinn Iordan et al, Sculpting new visual categories into the human brain, *Proceedings of the National Academy of Sciences* (2024). DOI: 10.1073/pnas.2410445121

Provided by University of Rochester

Samsung tipped to have smart glasses up its sleeve at Unpacked 2025

What you need to know

- Samsung might finally glimpse the long-rumored smart glasses at the Galaxy S25 series launch.
- It will likely be a sneak peek of the company's first AR glasses in mid-January.
- The smart glasses will reportedly be based on Samsung's Extended Reality (XR) platform.

Samsung might be prepping for its Galaxy S25 series launch, which is anticipated to happen in January 2025. While the trio of handsets are expected, a new report reveals that the company might have a smart glasses launch up its sleeve next month.

According to the Korean news outlet Yonhapnews, spotted by tipster Jukanlosreve on X, has indicated that Samsung might be showcasing a sneak peek of its first augmented reality (AR) glasses at the upcoming Galaxy S25 series Unpacked Event. It could be some sort of short video or an image reveal — likely a similar approach from the company where it showcased the Galaxy Ring for the first time during its 2024 Unpacked Event.

Just in: Samsung is set to unveil a prototype of its augmented reality (AR) glasses, currently in development, during the Galaxy S25 Unpacked event early next year, likely in the form of videos or images.Additionally, prior to revealing the prototype, Samsung plans to introduce…December 3, 2024

The upcoming smart glasses will likely rival the Meta's Ray-Ban glasses. They will be built on Samsung's Extended Reality (XR) platform, which is also tipped to be demoed at the upcoming Unpacked event. The Korean outlet further shares that the smart glasses will likely weigh 50 grams, coupled with the ability to make payments with the help of AI, gesture, and face recognition features.

While we might see a glimpse of the first smart glasses at the Unpacked event, which may include a prototype, the product is expected to be released sometime in the third quarter of 2025, notes the Korean publication. It is still unclear whether the alleged smart glasses are the ones that were rumored to be co-developed by Google and Qualcomm.

It's also been a while since we heard about Samsung's smart glasses, which were trademarked at the Intellectual Property Office in the U.K. last year. The product was then trademarked under the "Virtual reality headsets; Augmented reality headsets; Headphones; Smartphones; Smart glasses" categories.

Meanwhile, an alleged prototype was spotted before the launch of Apple Vision Pro. It included micro OLED displays powered by the Exynos 2200 chip and other highlighting features like eye-tracking cameras. However, it was soon scrapped after the Vision Pro's launch. Regardless, it is still encouraging to see Samsung still working on its version of smart glasses, which will likely be witnessed first at the Unpacked Event in 2025, which otherwise headlines the much-awaited Galaxy S25 series.

Neuroscientists discover a new pathway to forming long-term memories in the brain

Researchers from Max Planck Florida Institute for Neuroscience have discovered a new pathway to forming long-term memories in the brain. Their work, published in *Nature Neuroscience*, suggests that long-term memory can form independently of short-term memory, a finding that opens exciting possibilities for understanding memory-related conditions.

Our brain works diligently to record our experiences into memories, creating representations of our daily events that stay with us for short time periods. Current scientific theories of memory formation suggest that short-term memories are stored in what we can imagine as a temporary art exhibition in our brain before being cleared out for representations of new experiences.

A tiny fraction of these short-term memories—those most relevant to us—are moved to a more permanent exhibit, our long-term memory, where they are stored for days, years, or decades.

The most prevalent theories suggest this is a linear process. Our experience is encoded into a short-term memory, which is then consolidated into a long-term memory. However, a new study by Dr. Myung Eun Shin, Dr. Paula Parra-Beuno, and MPFI Scientific Director Dr. Ryohei Yasuda suggests that there may be another way to long-term memory formation.

"This discovery is akin to finding a secret pathway to a permanent gallery in the brain," said Dr. Shin, the study's lead author.

"The prevailing theory suggested a single pathway, where short-term memories were consolidated into long-term memories. However, we now have strong evidence of at least two distinct pathways to memory formation—one dedicated to short-term memories and another to long-term memories. This could mean our brains are more resilient than previously thought."

The key finding: Disrupting short-term memory formation did not block long-term memory

The research team focused on a specific enzyme in neurons called CaMKII, which is critical for short-term memory formation. Previously, they developed an optogenetic approach that uses light to temporarily deactivate CaMKII. With this tool in hand, the team set out to use light to block short-term memory formation in a mouse.

Mice prefer dark spaces and, when given a choice, will immediately enter a dark space from a brightly lit one. However, if a mouse is frightened in a particular dark space, the memory of the frightening experience will alter its behavior, and the mouse will avoid entering the dark space again.

When the research team used their tool to disrupt memory formation, even those mice that had a frightening experience an hour earlier entered the dark space, suggesting they had no memory of the experience. The scientists had successfully blocked short-term memory formation.

What happened next was surprising to the research team. A day, week, or even a month later, these mice were altering their behavior to avoid where they were previously frightened.

Mice that didn't seem to remember the frightening experience an hour after it occurred, showed clear evidence of remembering at later times. In other words, blocking short-term memory of the event did not disrupt long-term memory.

"We were initially quite surprised by this observation, as it was inconsistent with how we thought memories were formed. We didn't think it was possible to have a long-term memory of an event without a short-term memory. However, when we repeated these experiments and used multiple tools and approaches to verify our findings, we were convinced," says Dr. Shin.

"Rather than long-term memory formation being a linear process that requires short-term memory, a parallel pathway to long-term memory formation that bypasses short-term memory must exist."

Implications for memory dysfunction

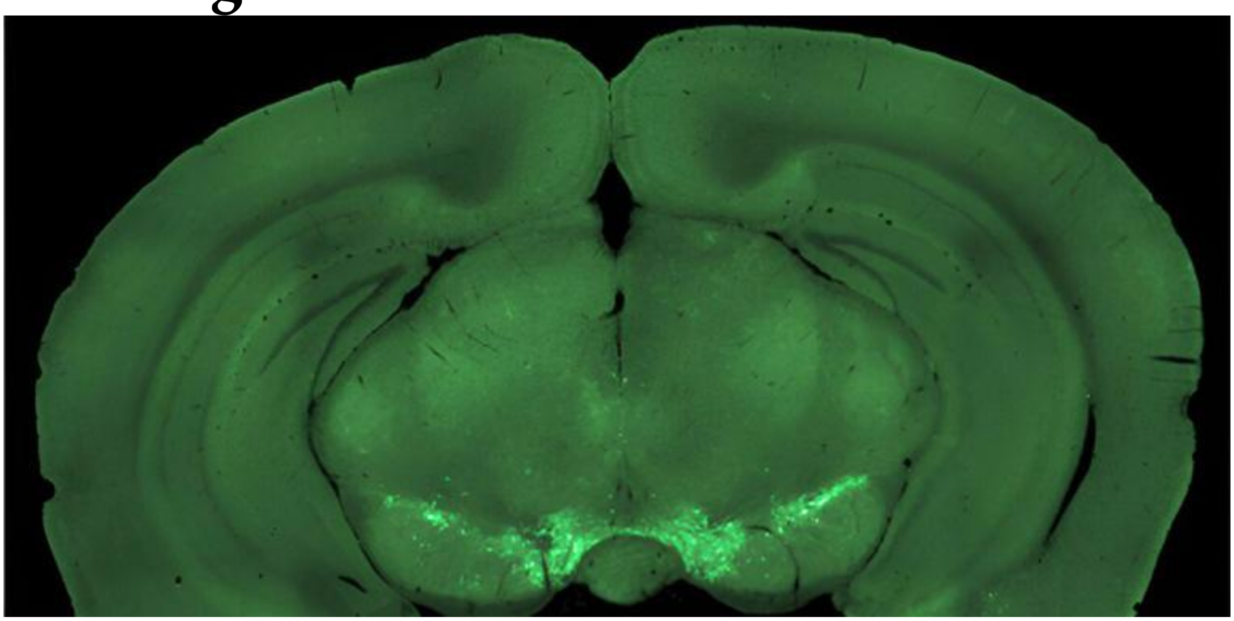
This study has changed the model of how memories are formed in the brain. Significant scientific advances often come after previous models of understanding are overturned, and the team is excited to see where this line of research will take them.

"This new finding has revised our understanding. We are now investigating how this newly discovered pathway to long-term memory formation occurs. We are excited to see what we can learn and what this could mean for preserving long-term memory retention, even when short-term memory is compromised by aging or cognitive impairment," says Dr. Yasuda.

More information: Shin, M.E., et al. Formation of long-term memory without short-term memory revealed by CaMKII inhibition, *Nature Neuroscience* (2024). DOI: 10.1038/s41593-024-01831-z

Provided by Max Planck Florida Institute for Neuroscience

Researchers show how dopamine pathways contribute to complex neural circuits that control goal-directed behavior



Two-photon microscopy helps researchers to observe brain mesocortical axon terminals (bright green) during a self-initiated lever-press task. Credit: M. Ohtake, K. Abe, M. Hasegawa, T. Itokazu, et al., doi 10.1117/1.NPh.11.3.033408.© Provided by Medical Xpress

Ever wondered how your brain decides when to act? Initiating actions with a specific goal in mind is a complex process. Previous research has identified certain parts of the brain and chemical signals involved. However, it remains unclear what information these signals convey and how they spark initiative.

Research titled "Encoding of self-initiated actions in axon terminals of the mesocortical pathway" reported in *Neurophotonics* dives into this mystery by investigating how mice time their actions in pursuit of rewards, exploring the role of a specific brain pathway called the mesocortical pathway, in the context of self-initiated movement.

They created a task for mice where they could press a lever at will and receive a reward. The mice would receive a better reward if they waited longer before pressing.

The research team found that a certain type of brain signal, mediated by dopamine and its "D2" receptors, plays a crucial role in these self-timed actions. That brain signal kicks into gear just before the mice decide to press a lever but, surprisingly, doesn't fire up when the mice respond to cues.

To understand better why that might be, the team used a novel imaging technique to observe the activity of these brain signals—just before the mice initiated their actions. They discovered a gradual increase in activity in certain parts of the brain about half a second before the self-timed presses.

Remarkably, this increase in activity occurred regardless of whether the mice pressed the lever quickly for a small reward or waited for a larger one.

According to senior author Takashi Sato, principal investigator in the Sato Brain Lab at the Medical University of South Carolina, "These findings offer tantalizing clues into the brain's inner workings and contribute to a deeper understanding of how brains control goal-directed behavior."

The research results raise some interesting questions: How might disruptions in the dopamine-mediated signaling pathway affect an individual's ability to time their actions effectively? Are there parallels between the mechanisms observed in mice and those at play in human decision-making processes? Could manipulating dopamine receptors lead to novel interventions for conditions characterized by impaired impulse control, such as addiction or ADHD?

More information: Makoto Ohtake et al, Encoding of self-initiated actions in axon terminals of the mesocortical pathway, *Neurophotonics* (2024). DOI: 10.1117/1.NPh.11.3.033408

Provided by SPIE

In 2025, the AI-infused world will require humans bring strategy and judgement by Optimove

OpenAI — an artificial intelligence research company — created ChatGPT and launched the tool in November 2022. With that, 2023 became the year of humans understanding genAI's capabilities. Then 2024 was the year of genAI's integration into marketing automation solutions.

Now, 2025 will be the year humans wrest control of genAI to ensure it is properly used for its role to deliver real-time, precision marketing messages.

With that said, as we look forward beyond genAI, the year 2025 will be the year of the human to bring strategy and judgement into marketing automation that will be further infused with AI.

Amidst this wave of automation and innovation, the role of the human marketer is more vital than ever. The new marketer is "Position-less" — who is a professional armed with versatile AI tools, capable of wearing multiple hats, yet anchored by irreplaceable human traits: strategy, judgment, and creativity.

These marketers will not only leverage AI's capabilities but also ensure that every decision, campaign, and interaction resonate on a human level.

Here's how the humans will lead the charge in navigating key trends shaping the future of marketing.

1. Hyper-personalization needs human sensitivity

AI excels at analyzing data to deliver personalized recommendations and content in real time. However, hyper-personalization isn't just about algorithms—it's about understanding the emotional and cultural context of customer interactions.

- **AI's contribution:** Predictive analytics and dynamic content generation enable real-time relevance.
- **Human role:** Marketers bring the emotional intelligence needed to ensure personalization doesn't feel intrusive but rather empathetic and meaningful.

Marketers are the architects who balance data-driven precision with the nuance of human connection.

2. Omnichannel integration requires human intuition

Creating a seamless customer journey across channels is essential, especially as consumers increasingly research online and purchase offline. While AI can map touchpoints and optimize engagement, it is marketers who shape the narrative.

- **AI's contribution**: Algorithms determine the best timing and channels for interactions.
- **Human role**: Marketers ensure that every touchpoint aligns with the brand's story and values, crafting an emotionally cohesive customer experience.

With omnichannel strategies, humans ensure the “seamless” is also “meaningful.”

3. Ethical data practices demand accountability

The rise of privacy regulations and the shift to zero-party data require brands to prioritize transparency and ethical data usage. Technology can handle compliance, but accountability is a human responsibility.

- **AI’s contribution**: Tools streamline data collection and segmentation.
- **Human role**: Marketers ensure campaigns respect privacy, foster trust, and use data ethically to deepen customer relationships.

Marketers are the stewards of ethical practices, ensuring technology serves both customers and brands.

4. AI-Driven Creativity Still Needs Human Judgment

As noted, generative AI can create email copy, product recommendations, and even dynamic website content at scale. Yet it lacks the strategic foresight and emotional resonance required for effective marketing.

- **AI’s contribution**: Automates content creation, accelerating execution.
- **Human role**: Marketers oversee AI outputs, ensuring alignment with brand identity and long-term goals.

Marketers remain the creative force behind every campaign, using AI as a tool, not a replacement.

5. Beyond 2025: Advanced technologies require Vision

Emerging tools like emotion AI, quantum computing and digital twin technology promise to revolutionize marketing. However, their potential depends entirely on how marketers apply them.

- **AI's contribution**: Enhances targeting, personalization, and customer experience.
- **Human role**: Marketers envision real-world applications that solve problems and enhance engagement.

Marketers must pair technology's possibilities with human ingenuity to drive meaningful innovation.

The human edge in an AI-driven world

In 2025, marketing success won't hinge solely on the tools and technologies brands adopt, but on how humans wield them. It will be the "Position-less Marketer" who embodies this shift, blending technical prowess with strategic vision, creativity, and empathy.

As AI accelerates what's possible, marketers must remain at the helm, ensuring every campaign feels authentic, every interaction resonates, and every innovation serves a purpose.

The future of marketing belongs to those who can seamlessly integrate technology with humanity. The Position-less Marketer is not just a response to AI's rise—it's the key to unlocking its full potential.

This is a new era of marketing, where humans and machines work hand in hand to deliver exceptional experiences. Now, use your best strategy and judgement.

How Samsung could finally unlock smart glasses' true potential

It might not feel like it yet, but the world of smart glasses is heating up.

On top of new entries from companies like Xreal, Meta took the next steps with its Ray-Ban smart glasses this year, imbuing them with AI and adding even more potential for future uses down the line. As I've written previously, Meta's Ray-Ban smart glasses are arguably my favorite (and maybe the most underrated) gadget of the year.

They have great audio capabilities, they make taking pictures and videos easy, and they actually look like normal, Ray-Ban, glasses. When it comes to style and capability, they stand alone in the smart glasses category.

At least for now...

Samsung enters the chat

Looks like Meta might not be alone in the world of fashionable smart glasses much longer.

According to a report this week from Korean outlet *Yonhap News*, Samsung may be preparing to launch its own pair of smart glasses soon, potentially during January's annual Galaxy Unpacked event where it typically introduces its flagship Galaxy phones.

On one hand, that's to be expected — Meta has already made a clear case that smart glasses with a camera and solid audio are a marketable commodity. On the other hand, it could represent one of the biggest sea changes in smart glasses we've seen yet.

Let me explain.

Meta's glasses are great. They do a lot more than you might expect for a relatively nascent product category and they might do even more in the future thanks to Meta AI which imbues the glasses with a bit of computer vision.

But as solid as they are, they're still lacking something — something that actually has almost nothing to do with the glasses themselves. That something is an ecosystem.

Competitors like Xreal offer more augmented reality but in a bigger form factor. (Image credit: XREAL)

Smart glasses, for all of their surprising use cases, still need to be coupled with a real computer, and in that case, that computer is your phone. Your phone is the only reason that Meta's Ray-Ban glasses are useful and thanks to that synergy they can play music, announce turn-by-turn navigation in your maps apps, take calls, and more.

But for everything Ray-Ban glasses *can* do thanks to your phone, there are just as many things that they can't. That has almost nothing to do with the glasses themselves or their technical limitations, but a lot to do with your phone.

Meta's Ray-Bans just don't have the deep system-level access to your phone to bring them the extra mile. Imagine for a moment a pair of glasses that plays nice with *everything* your phone does — I'm talking text messages, calls, voice assistants, timers, calendars, you name it.

Sounds useful, right? That's exactly what Samsung might have to offer.

A smarter pair of smart glasses

A pair of Samsung smart glasses has no real limitations when it comes to which apps it has access to and which it doesn't, and for that reason, they could unlock the true potential of the category.

Paired with system-level access, Samsung's rumored smart glasses would be a real-functional extension of your phone in the same way that a watch is — maybe even more so since it can capture media as well.

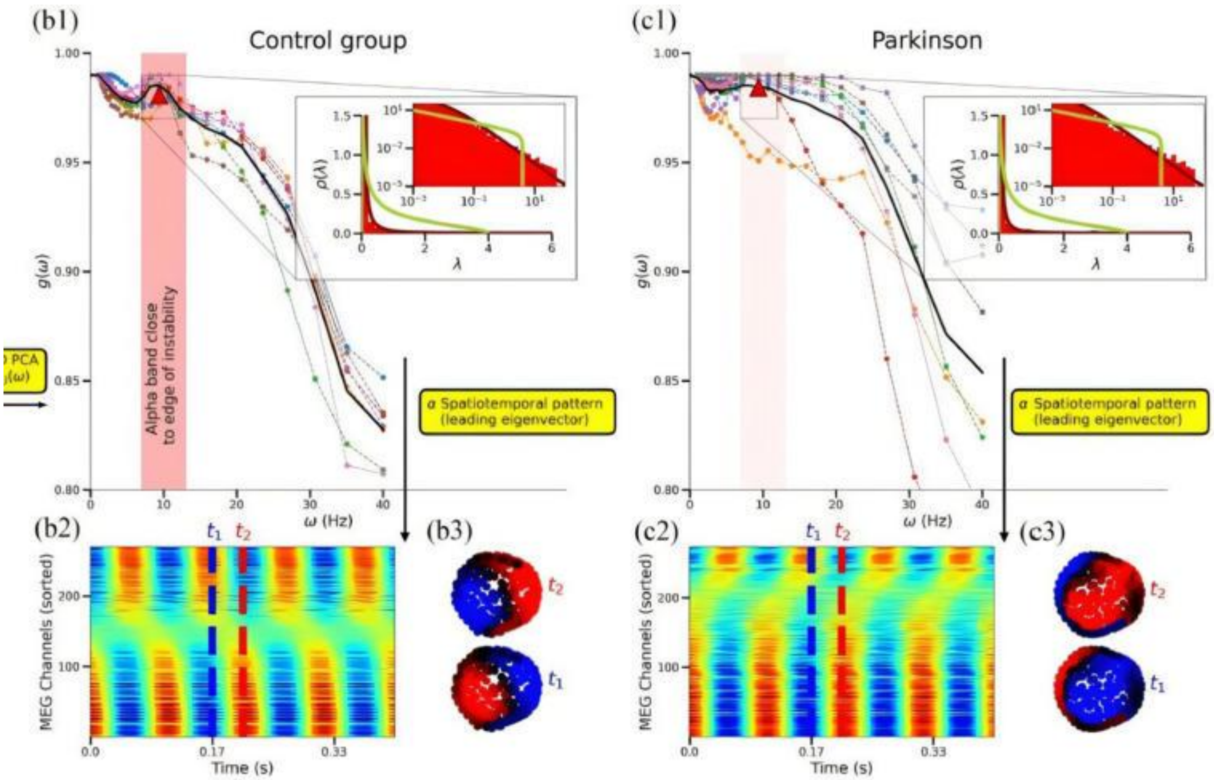
Think about it. A pair of deeply integrated smart glasses could take pictures and videos and send them directly to your photos app; it could take calls; it could send messages through voice; it could integrate with your phone calendar and send you reminders; it could interact with your phone's voice assistant to search the web or, heck, draft an email for you. By borrowing your phone's ecosystem and compute power, I can't think of anything that smart glasses *can't* do.

In short, they could cease on basically all the shortcomings of Meta's Ray-Bans.

This is all hypothetical for now, but when you start to unpack the possibilities, a pair of smart glasses made by a company that also manufactures phones just makes sense. It'd still be pretty far off from the AR future promised by prototypes like Meta's Orion, but it would also easily be the best pair of phone-like smart glasses we've seen yet.

As much as I love Meta's Ray-Ban glasses, favorites are a fleeting thing and if Samsung really pulls the trigger, we may have a new king of smart glasses.

Assessing synchronized activity in the human brain through frequency-dependent covariance analysis



On the top vertical axes, g(ω) is the frequency-dependent covariance matrix. Top plots show the activity of several channels of EEGs near the head. Image (c2) reveals a different organization of the distance to criticality across frequency bands compared to (c1). Credit: American Physical Society

This year is the centennial anniversary of German psychiatrist Hans Berger's invention of electroencephalography (EEG), a way to record electrical activity in the brain, now called brainwaves or neural oscillations. Amazingly, Berger was motivated after an incident in his military years when he believed he had spontaneously transmitted something from his brain to his sister during a sudden moment when he was nearly killed in an accident, and his sister several kilometers away insisted their father get in touch with him.

Years later Berger called it "spontaneous telepathy."

Berger's EEGs record electrical activity in the brain, enabling evaluation of brain activity that originates in neurons in underlying brain tissue, typically showing waves whose frequencies correlate with how awake a person is. The years since Berger's invention and discovery have, of course, revealed a great deal about the activity and brainwave patterns in the brain.

It is believed that some biological neural networks operate very close to phase transitions between dynamical regions that are ordered or disordered. Called the critical brain hypothesis, it posits that avalanche criticality and edge of chaos criticality are especially important in studies of brain function and dysfunction.

Evidence suggests it is actually near-critical states, as opposed to a singular state of a strictly critical state, that may be closer to observations and a better explanation for how the brain operates; brain states on the verge of criticality enhance the capacity for the brain to process information, store information and transmit it.

Now a team from the University of Granada in Spain has presented a new framework to explore signs of criticality across different brainwave frequency bands and constructed a more comprehensive picture of brain activity. In doing so, they have seen significant differences in signatures of criticality between data on healthy patients and people with Parkinson's disease.

Lead author Rubén Calvo and his collaborators' work has been published in *Physical Review Letters*.

Earlier work to validate the critical brain hypothesis used statistical analysis—time-averaged neuron firing rates. Calvo and his team took a deeper look, analyzing the way the distribution of how the firings occur over time. In particular, they used a "covariance matrix" to flesh out patterns within the data using a statistical technique called principal-component analysis (PCA).

PCA is a widely used technique to explain data of many variables by calculating new variables that are linear combinations of the original variables; they best explain the variance in the data.

Transforming the data in this way will create a new coordinate system with the greatest variance lying along the first coordinate, the second greatest variance (after the first coordinate's variance is removed) is along the second, and so on. PCA analysis simplifies the data structure while making the explanatory variables more obvious.

To minimize known limitations with the PCA technique, the Granada group used frequency-dependent PCA, where frequency is that of brainwaves, such as those in the classifications labeled gamma, beta, alpha, theta and delta. Brain activity presents as diverse, time-dependent oscillations across many frequency bands, together with more complex nonperiodic oscillations.

Together they describe short-lived synchronizations of neurons, which is crucial for transmitting and integrating information between regions of the brain. The effectiveness of this depends on the distance to the edge of instability/criticality in the frequency band, the distance being in frequency space (viz. after a Fourier Transform).

The covariance matrix is the correlation between the firing rates of the many pairs of neurons. Solving for the covariance matrix gives a list of eigenvalues and eigenvectors—the leading eigenvectors represent directions of maximum variability, and associated eigenvalues represent the distance along that eigenvector.

This allows the very complicated dataset of firing rates to be described in a much simpler, low-dimensional manner. With frequency-dependent firing rates, Calvo and his group showed that the spectrum of eigenvalues can be used to deduce the distance to criticality for any frequency band.

"Therefore," they write, "the frequency-dependent covariance matrix allows us to observe fingerprints of criticality in datasets with a nontrivial temporal organization and unveil dynamical features that could not be uncovered through standard analyses of the integrated longtime covariance." Switching to multi-frequency space reveals dynamical processes that static covariances cannot.

To test their methodology, they used firing rate data from patients with Parkinson's disease, a movement disorder of the nervous system. Measuring the distances from criticality, they discovered that "there is a significantly broader interval of frequencies close to the edge of instability compared to the control group"—more frequencies close to the instabilities in frequency space.

The brainwaves of Parkinson's patients have significantly different structures in space and time. They conclude that their decomposition of data on brain activity could be a "promising avenue" for future research in understanding the differences between healthy brain states and pathological states.

More information: Rubén Calvo et al, Frequency-Dependent Covariance Reveals Critical Spatiotemporal Patterns of Synchronized Activity in the Human Brain, *Physical Review Letters* (2024). DOI: 10.1103/PhysRevLett.133.208401

Neuroscience study taps into brain network patterns to understand deep focus, attention

Credit: Pixabay/CC0 Public Domain© Provided by Medical Xpress

From completing puzzles and playing music, to reading and exercising, growing up Dolly Seeburger loved activities that demanded her full attention. "It was in those times that I felt most content, like I was in the zone," she remembers. "Hours would pass, but it would feel like minutes."

While this deep focus state is essential to highly effective work, it's still not fully understood. Now, a new study led by Seeburger, a graduate student in the School of Psychology, alongside her advisor, Eric Schumacher, a professor in the School of Psychology is unearthing the mechanisms behind it.

The interdisciplinary Georgia Tech team also includes Nan Xu, Sam Larson and Shella Keilholz (Coulter Department of Biomedical Engineering), alongside Marcus Ma (College of Computing), and Christine Godwin (School of Psychology).

The researchers' study, "Time-varying functional connectivity predicts fluctuations in sustained attention in a serial tapping task," published in *Cognitive, Affective, and Behavioral Neuroscience*, investigates brain activity via fMRI during periods of deep focus and less-focused work.

The work is the first to investigate low-frequency fluctuations between different networks in the brain during focus, and could act as a springboard to study more complex behaviors and focus states.

"Your brain is dynamic. Nothing is just on or off," Seeburger explains. "This is the phenomenon we wanted to study. How does one get into the zone? Why is it that some people can sustain their attention better than others? Is this something that can be trained? If so, can we help people get better at it?"

The dynamic brain

The team's work is also the first to study the relationship between fluctuations in attention and the brain network patterns within these low-frequency 20-second cycles.

"For quite a while, the studies on neural oscillations focused on faster temporal frequencies, and the appreciation of these very low-frequency oscillations is relatively new," Seeburger says. "But, these low-frequency fluctuations may play a key role in regulating higher cognition such as sustained attention."

"One of the things we've discovered in previous research is that there's a natural fluctuation in activity in certain brain networks. When a subject is not doing a specific task while in the MRI scanner, we see that fluctuation happen roughly every 20 seconds," adds co-author Schumacher, explaining that the team was interested in the pattern because it is quasi-periodic, meaning that it doesn't repeat exactly every 20 seconds, and it varies between different trials and subjects.

By studying these quasi-periodic cycles, the team hoped to measure the relationship between the brain fluctuation in these networks and the behavioral fluctuation associated with changes in attention.

Your attention needed

To measure attention, participants tapped along to a metronome while in an fMRI scanner. The team could measure how "in the zone" participants were by measuring how much variability was in each participant's taps—more variability suggested the participant was less focused, while precise tapping suggested the participant was "in the zone."

The researchers found that when a subject's focus level changed, different regions of the brain synchronized and desynchronized, in particular the fronto-parietal control network (FPCN) and default mode network (DMN), The FPCN is engaged when a person is trying to stay on task, whereas the DMN is correlated with internally-oriented thoughts (which a participant might be having when less focused).

"When one is out-of-the-zone, these two networks synchronize, and are in phase in the low frequency," Seeburger explains. "When one is in the zone, these networks desynchronize."

The results suggest that the 20-second patterns could help predict if a person is sustaining their attention or not, and could provide key insight for researchers developing tools and techniques that help us deeply focus.

The big picture

While the direct relationship between behavior and brain activity is still unknown, these 20-second patterns in brain fluctuation are seen universally, and across species.

"If you put someone in a scanner and their mind is wandering, you find these fluctuations. You can find these quasi-period patterns in rodents. You can find it in primates," Schumacher says. "There's something fundamental about this brain network activity."

"I think it answers a really fundamental question about the relationship between behavior and brain activity," he adds. "Understanding how these brain networks work together and impact behavior could lead to new therapies to help people organize their brain networks in the most efficient way."

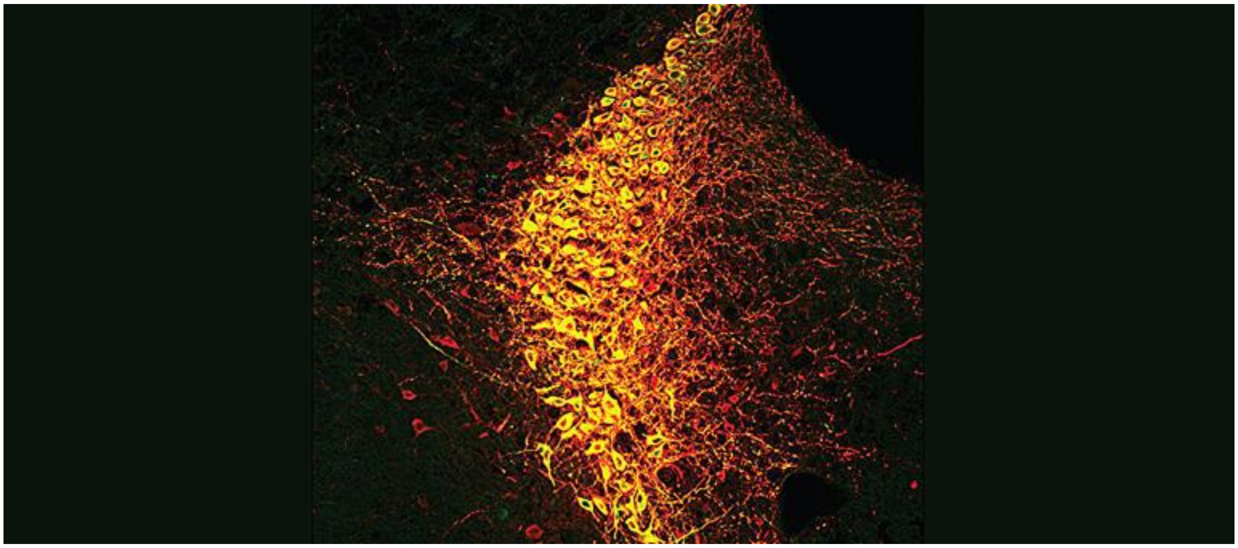
And while this simple task might not investigate complex behaviors, the study could act as a springboard to move into more complicated behaviors and focus states.

"Next, I would like to study sustained attention in a more naturalistic way," Seeburger says. "I hope that we can further the understanding of attention and help people get a better handle on their ability to control, sustain, and increase it."

More information: Dolly T. Seeburger et al, Time-varying functional connectivity predicts fluctuations in sustained attention in a serial tapping task, *Cognitive, Affective, & Behavioral Neuroscience* (2024). DOI: 10.3758/s13415-024-01156-1

Provided by Georgia Institute of Technology

The brain's state of attention is shaped by a handful of neurons, study shows



Noradrenergic neurons in the locus coeruleus (LC) play a key role in the transition from a focused to an alert state. The image shows these neurons in a mouse brain, revealed by immunohistochemical staining. Credit: UNIGE / ETH Zurich

What enables the brain to go from intense concentration to a heightened state of alertness? A study carried out by neuroscientists at the University of Geneva (UNIGE), in collaboration with ETH Zurich, shows that a brain region called locus coeruleus (LC) and the neurotransmitter noradrenaline act as conductors, reorganizing brain functions according to the mental demands of the moment.

The study, published in *Nature Neuroscience*, demonstrates that the way the locus coeruleus is triggered enables us to switch from one state of concentration to another. This discovery could change the way elite sportsmen and women train to achieve their goals.

How do athletes achieve the extraordinary mental clarity and precision needed to succeed in their discipline? The answer lies in the brain's remarkable ability to focus, eliminating distractions to concentrate on a single task.

This phenomenon, often described as "being in the zone," is a critical skill not just for athletes, but for anyone facing a challenging task—whether it's taking an exam or mastering a musical instrument. At times, however, these people also need to be fully aware of their environment, especially when it comes to spotting potential dangers.

A handful of neurons

In this study, neuroscientists from UNIGE and ETH investigated what allows the brain to shift between intense focus and heightened awareness. The research team focused on the locus coeruleus (LC), a small region in the brainstem that produces noradrenaline, a neurotransmitter involved in regulating arousal.

"It's small and its location deep within the brain was a challenge from the outset, making it difficult to observe—and impossible to manipulate—in humans. For these reasons, we turned to mice where the LC consists of only about 3,000 neurons, but these neurons can still exert a significant influence over the 75 million neurons that make up the mouse brain," explains Valerio Zerbi, assistant professor in the Department of Psychiatry and the Department of Basic Neurosciences at the UNIGE Faculty of Medicine, and initiator of the study.

To overcome this challenge, his team collaborated with Johannes Bohacek's laboratory at ETH Zurich. Using advanced techniques such as optogenetics to artificially manipulate LC neurons and photometry to measure noradrenaline release, the researchers were able to explore LC function.

Functional Magnetic Resonance Imaging (fMRI) provided the first empirical evidence into how LC stimulation affects brain activity across different regions, shedding light on the LC's role in dynamically modulating attention and focus.

A question of rhythm

Neuroscientists discovered that triggering the LC three times a second in a continuous manner—so-called "tonic" activity—had different consequences than triggering the same frequency over a short period of time—so-called "burst" activity.

"When the LC is triggered in bursts, more noradrenaline is released, and the brain's sensory functions are prioritized. This sensory brain mode enables mice to be more alert to the environment around them," explains Zerbi.

Conversely, when the LC is triggered in a moderate tonic mode, less noradrenaline is released by the LC and brain regions such as the prefrontal cortex and hippocampus are activated. These two structures are known for processing information and are conducive to reflection and intense attention.

Controlling the locus coeruleus for performance

"While cutting-edge equipment and meticulous training are certainly part of the equation, the secret of top athletes may well lie in their mastery over their LC. By finely tuning its activity, they can switch between states of intense focus and broad awareness, performing at their peak when it matters most," concludes Zerbi.

Also, thanks to the findings of this study, brain imaging could help sportsmen and women to make better use of their LC, notably by using neurofeedback approaches, a technique that uses devices to monitor brain activity in real time to enable a person to regulate it based on visual feedback.

More information: Christina Grimm et al, Tonic and burst-like locus coeruleus stimulation distinctly shift network activity across the cortical hierarchy, *Nature Neuroscience* (2024). DOI: 10.1038/s41593-024-01755-8. www.nature.com/articles/s41593-024-01755-8

Provided by University of Geneva

AI robotics will take on human labor so humans can 'engage their brains better,' former Amazon exec says

Robots will replace human labor, to some extent and over time, but people shouldn't be too worried, according to a long-time Amazon executive with a new AI supply chain start-up.

"Robotics will drive a ton in labor savings over time," Dave Clark, the former CEO of Amazon's consumer business and now founder of the AI supply-chain start-up auger, said Monday during Fortune's Brainstorm AI conference in San Francisco. "Unfortunately, we've made productivity sort of a dirty word. But we keep finding better ways to engage people's brains."

"There's too much hand wringing about it," Clark added, alluding to expert warnings and concerns that future advances in AI technology may reduce or replace human labor to the benefit of corporations looking to save money on wages.

With two decades experience as a supply-chain executive, Clark admitted that companies are always looking to "extract maximum cost out of the system," but the cost of labor is actually less impactful than things like transportation and a lack of forecasting.

Google patents smart glasses with display, speaker & eye-tracking

Many people would say that the Google Glass project was ahead of its time, and I'd agree. Well, it's possible Google will try again, as the company just patented smart glasses with a built-in display, speakers, eye-tracking, and more.

Google could have plans to launch a new pair of smart glasses

This patent surfaced in China, as it was patented with CNIPA (China's National Intellectual Property Administration), China's certification agency. First and foremost, this patent indicates that these glasses won't be a standalone product. Google allegedly has plans to offload processing to a smartphone, so the glasses will need to be connected to a smartphone.

In addition to a built-in display, speaker, and eye-tracking, these glasses also have a microphone included, and cameras, of course. Based on this patent, these glasses mainly rely on contextual data such as location to provide suggestions or accept commands.

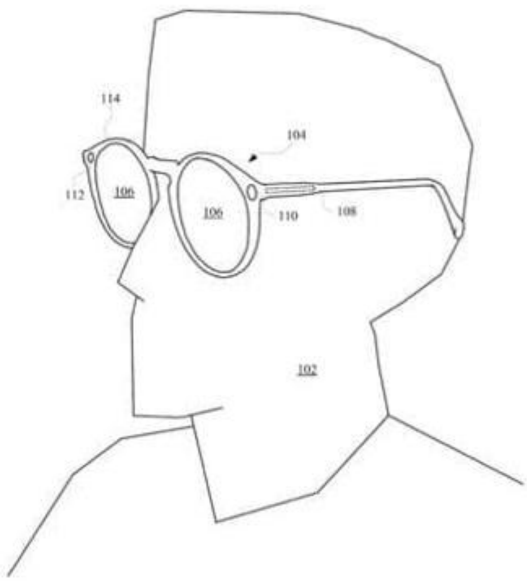
Users can interact with glasses via touch, voice, or gesture input. Something called 'gaze tracking' is also a part of Google's plans. Built-in cameras are included to identify your surroundings, and the displays can provide information and navigation.

Processing will be offloaded to a smartphone

Needless to say, Google's plan to offload processing to smartphones will save battery life. So these glasses could end up excelling in that regard if they ever become a reality. This is just a patent at this point, so don't get your hopes up just yet.

Chances are that Google will come up with such a product sooner or later, though. Samsung is allegedly working on its XR device and AR glasses, while Meta partnered up with Ray-Ban to introduce rather interesting smart glasses that my colleague fell in love with.

Is it time for Google to revive Google Glass… well, kind of? Well, it may be. This could be the ideal time for the company to do just that. Wearing various tech gadgets is normalized, while the technology caught up.



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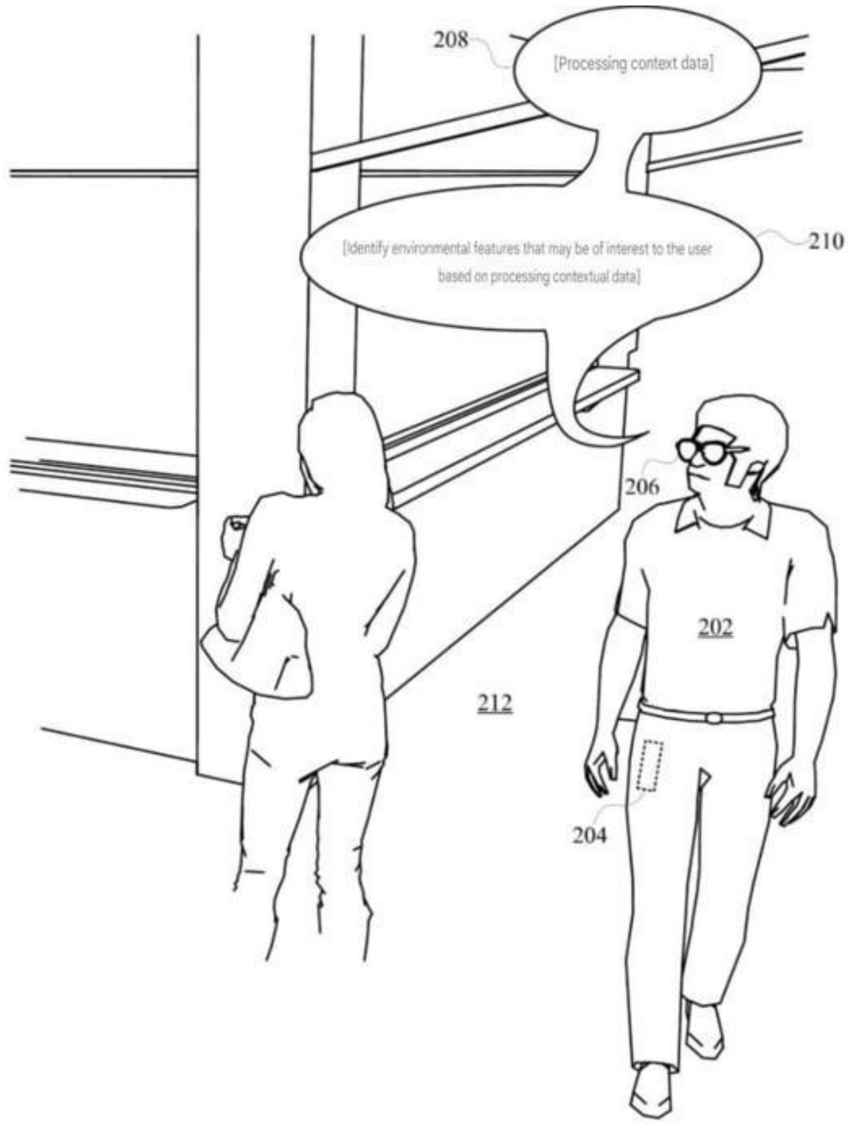
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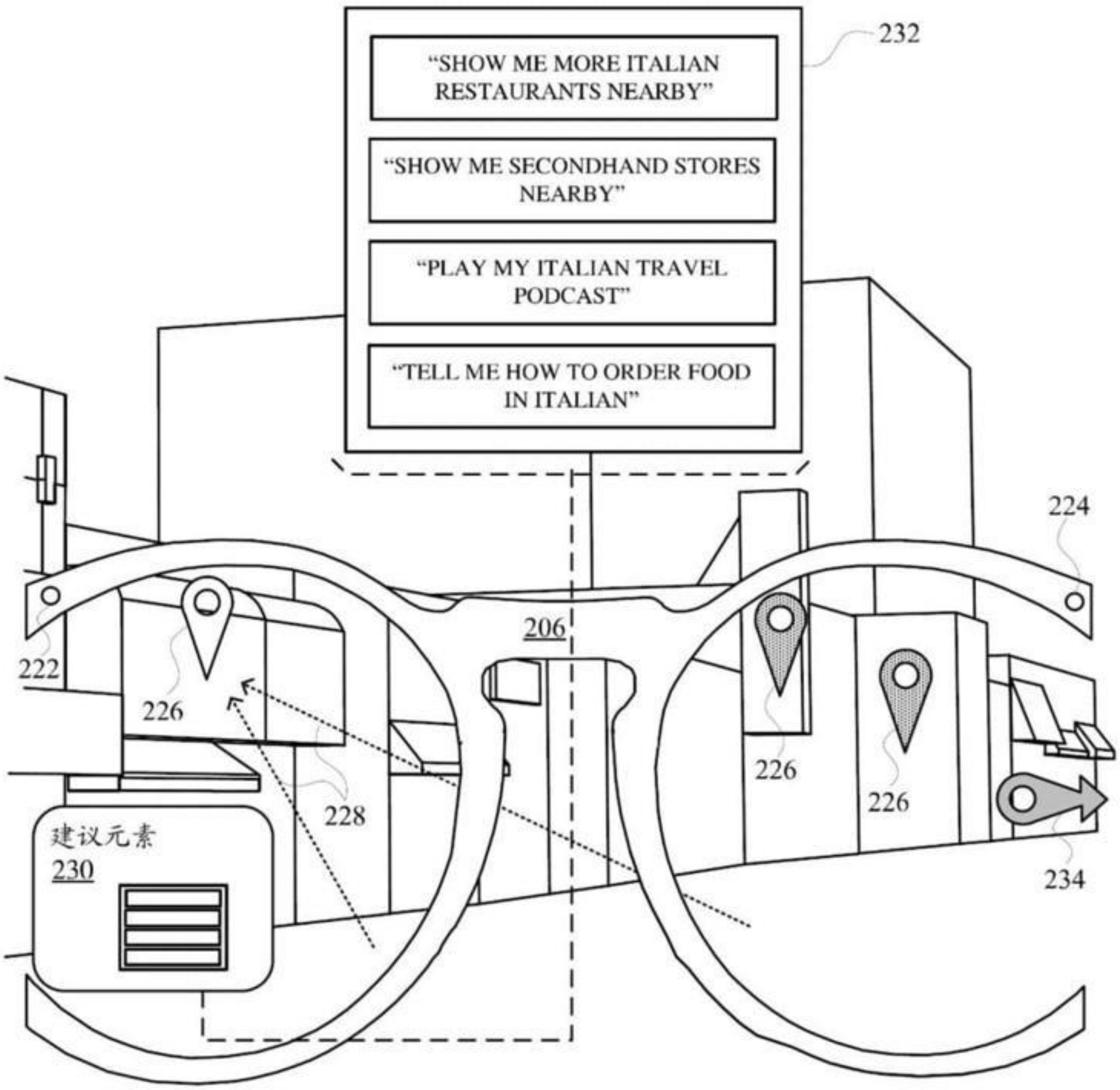
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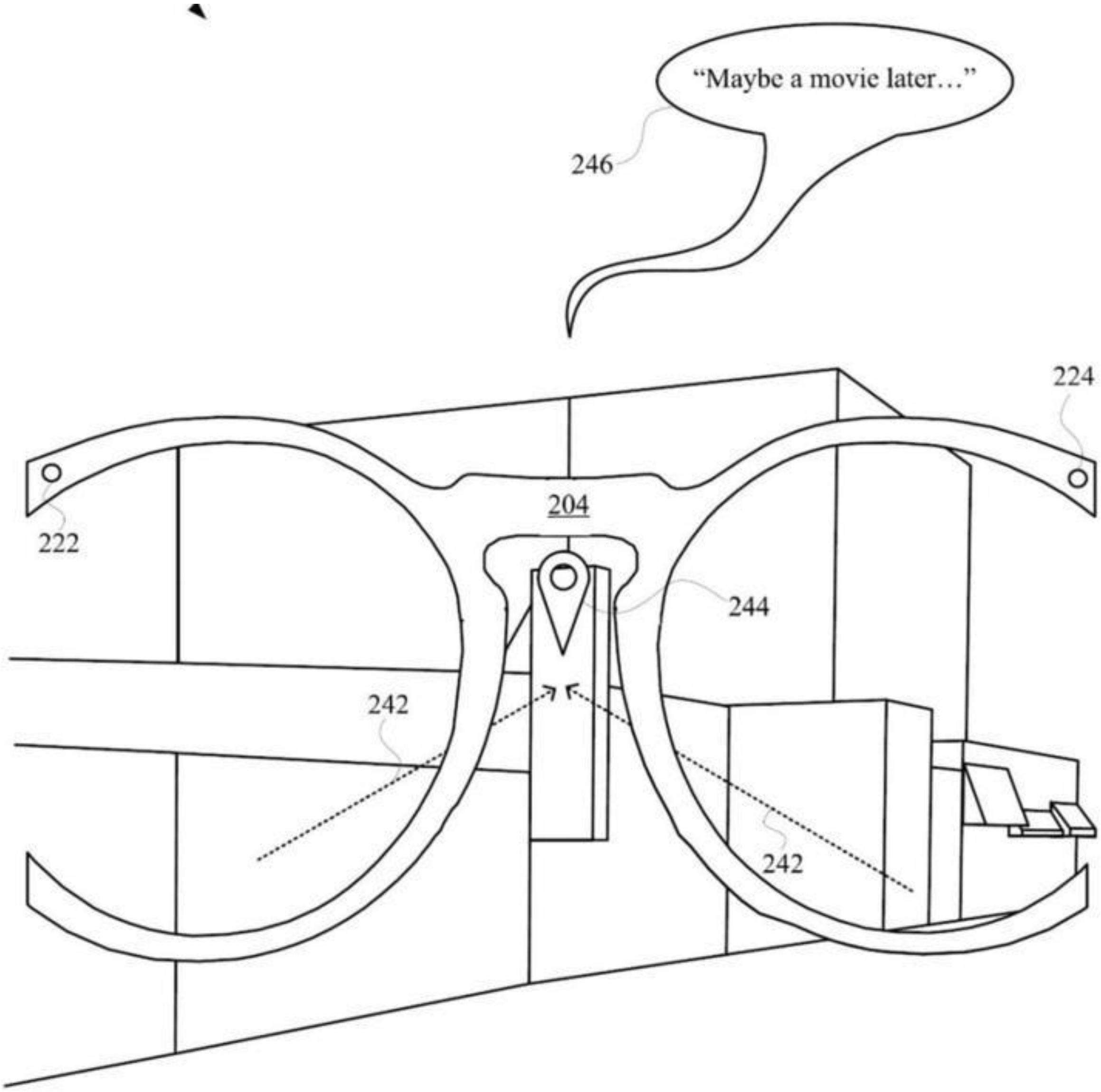
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The next Apple Watch Ultra could have satellite texting

Apple enabled non-emergency satellite messaging from iPhones earlier this year. According to *Bloomberg*'s Mark Gurman, it may do the same for the next Apple Watch Ultra in addition to adding the long-rumored blood-pressure monitoring feature.

Satellite messaging on the Watch Ultra has been rumored since before we even knew what Apple's XL-sized sporty take on its smartwatch line would be called. According to Gurman's description, it would work like it does on the iPhone, letting you send text messages from the watch without a cellular or Wi-Fi connection.

He also reports that Apple is swapping out Intel modems in the Apple Watch for a component from MediaTek but doesn't have any plans yet to use its upcoming in-house modems for the wearables. The new component included in "at least some models" could also support RedCap, the 5G service intended for wearables and IoT that sacrifices extra antennas and maximum bandwidth to reduce cost and extend battery life.

Adding satellite service could help Apple lure some Garmin inReach fans who might want to have one less thing to carry even if the inReach's hundreds of hours of battery life still win out for extended hikes. Presumably, service would be provided by Globalstar, Apple's satellite partner for the iPhone that it bought a 20 percent stake in last month.

As for blood-pressure monitoring, Gurman says that it “may arrive as soon as 2025 as well,” but he reminds us that the feature has been delayed in the past. Like sleep apnea detection and other health features of the Apple Watch, this feature wouldn't offer specific measurements but could let you know if you seem to be experiencing hypertension.

How the brain structure that produces norepinephrine also helps control visual attention

The locus coeruleus (LC) is a small region of the brainstem that produces norepinephrine, a chemical with powerful effects on arousal and wakefulness which plays an important role in the body's response to stress or panic. Now, research from the University of Chicago shows it plays a specific role in visual sensory processing as well.

In a study, titled "Locus coeruleus norepinephrine selectively controls visual attention" and published in *Neuron*, neuroscientists artificially increased neuronal activity in the LC by briefly shining light on genetically modified neurons. They saw that this manipulation selectively enhanced performance in non-human primates performing a visual attention task, underscoring the crucial role that attention plays in sensory perception.

"We want to understand what changes in your brain when you pay attention to something in the environment, because attention greatly affects your ability to discern stimuli," said John Maunsell, Ph.D., the Albert D. Lasker Distinguished Service Professor of Neurobiology and Director of the Neuroscience Institute at the University of Chicago, and co-author of the study.

"Now we have found a brain structure that has strong signals related to whether the subjects are paying attention to a stimulus or not, and we see big differences in how its neurons respond depending on where that attention is directed."

Maunsell and co-author Supriya Ghosh, Ph.D., a postdoctoral researcher, focus their studies on how neurons in different areas of the brain change to represent sensory input when a subject is paying attention to a stimulus or not. For example, activity of neurons in the cerebral cortex may increase by 10–25% when a subject pays attention to the stimuli those neurons represent.

Previous research has shown that LC activation, coupled with its ensuing norepinephrine production, might improve performance on tasks that require attention to discern between visual stimuli.

Ghosh, who specializes in subcortical brain structures, suggested that the LC might be a good candidate to study for these effects. The team trained two monkeys to perform a visual task in which they paid attention to the left or right side of a screen. First, a sample image would appear on both sides of the screen.

Next, after a delay, a test image would appear on one side of the screen. The monkey would report if that image was oriented differently than the sample shown earlier on that side of the screen by moving its eyes to one of two targets. The researchers recorded neuron activity in the LC during the task and saw that activity increased greatly—and only—when the animal attended to the image that appeared on the side of the screen monitored by those neurons.

To see if there was a causal relationship between this increased activity and performance, they also used a method called optogenetics to increase activity in the LC while the animals were performing the task. Optogenetics allows researchers to selectively control the activity of norepinephrine-expressing cells via light.

First, they introduce a genetic modification that causes neurons to produce a light-sensitive protein called opsin, the same type of protein that photoreceptors in the eye use to detect light. When they shine a special light on these neurons, the opsin causes the neurons to fire.

Optogenetically boosting the responses of the neurons drastically improved the animals' ability to differentiate the shapes on the corresponding half of the screen, without affecting motor processing.

"This kind of artificial enhancement of that activity did not interfere with other cognitive factors either, such as motor actions or decision-related activities," Ghosh said. "So, it could selectively contribute to the perceptual sensitivity in a very precise way."

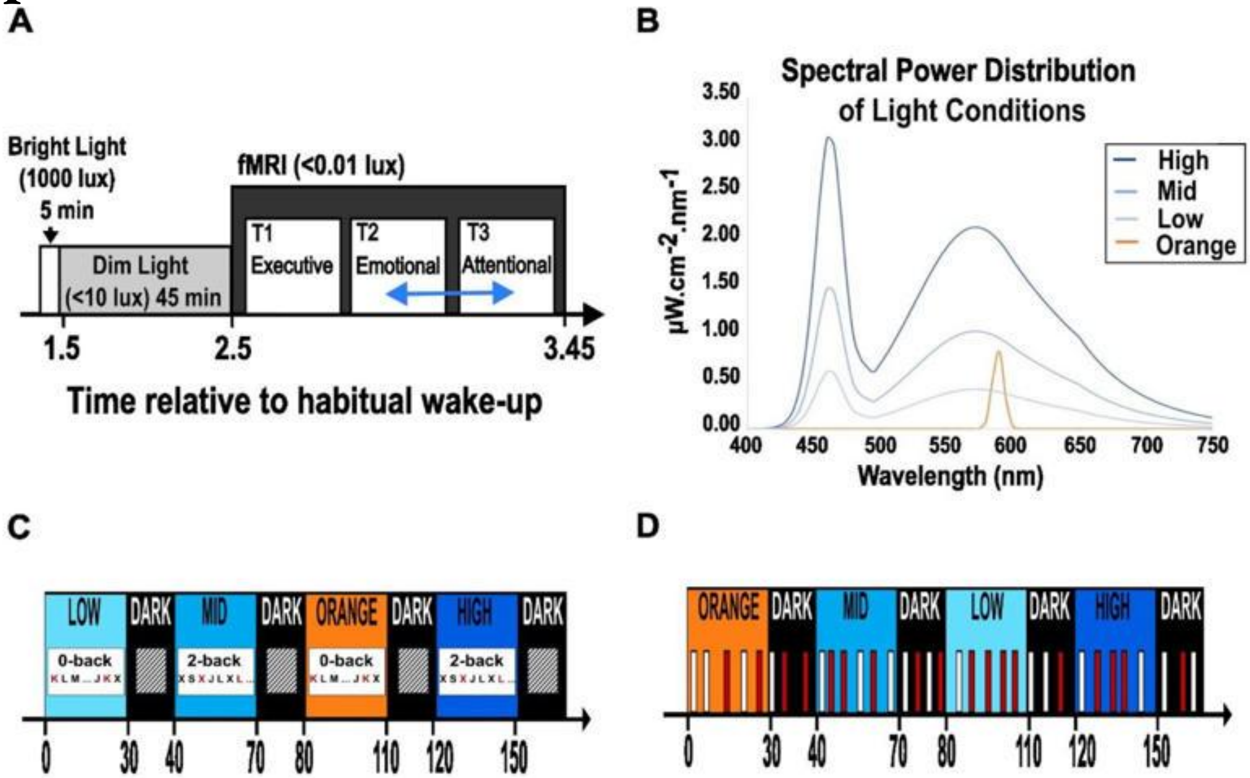
Distinguishing the effects of attention from other factors, like decision-making or motor movements, is crucial, Ghosh said. Those processes take place in other parts of the brain, and can contribute to performance independently. Understanding how a relatively small brain structure like the LC impacts such an important function as attention is also one step toward solving the overall puzzle of the brain.

"Every time we get more information about the likely contribution of a given brain structure, or how broad the range of functions of a given structure might be, that gives us much more power to understand the relationships among them," Maunsell said. "No one part of the brain does interesting behaviors by itself."

More information: Locus coeruleus norepinephrine contributes to visual spatial attention by selectively enhancing perceptual sensitivity, *Neuron* (2024). DOI: 10.1016/j.neuron.2024.04.001. www.cell.com/neuron/fulltext/S0896-6273(24)00239-3

Provided by University of Chicago

Higher light levels may improve cognitive performance



Experimental protocol. (A) Overall timeline. After prior light history standardization, participants performed executive (always first), emotional and attentional tasks (pseudo-randomly 2nd or 3rd, blue arrow). As the attentional task included fewer light conditions, it is not considered in the present manuscript (see methods for more details). (B) Spectral power distribution of light exposures. Monochromatic orange: 0.16 mel EDI lux; Polychromatic, blue-enriched light (6500K); LOW, MID, HIGH: 37, 92, 190 mel EDI lux. For the present analyses, we discarded color differences between the light conditions and only considered illuminance as indexed by mel EDI lux, constituting a limitation of our study. See Suppl. Table S2 for full details. (C-D) Tasks procedures. Time is reported in seconds relative to session onset; participants were pseudo-randomly exposed to the 4 light conditions. (C) Executive task: alternation of letter detection blocks (0-back) and working memory blocks (2-back). (D) Emotional task: lure gender discrimination of vocalizations (50% angry (red), 50% neutral (white). Credit: eLife (2024). DOI: 10.7554/eLife.96576.1© Provided by Medical Xpress

Exposure to higher levels of light can help people feel more awake and increase cognitive performance, probably by influencing the activity of parts of a brain region called the hypothalamus, according to new research.

The study, published in *eLife*, is described by the editors as of fundamental importance, and represents a key advancement to our understanding of how different levels of light affect human behavior. The strength of evidence is praised as compelling, supporting the authors' analyses of the complex interplay between light exposure, hypothalamic activity, and cognitive function.

With further research, the findings could be used to inform various light therapy treatments to increase an individual's quality of sleep and affective state, and help them feel more awake and perform tasks better throughout the day.

The biological effects of light exposure have been well documented in recent years. Higher illuminance has been shown to stimulate alertness and cognitive performance. These effects primarily rely on a subclass of light-sensitive cells in the retina, called ipRCGs.

These cells project to multiple areas of the brain, but projections are most densely found within the hypothalamus, which is typically associated with the regulation of circadian rhythms, sleep and alertness, and cognitive functions. However, this knowledge of the brain circuitry underlying the biological effects of light has almost entirely stemmed from studies in animals.

"Translating findings on how light exposure affects the brain in animal models to humans is a difficult process, as the later maturation of the cortex in human beings enables much more complex cognitive processing," explains lead author Islay Campbell, former Ph.D. student at the GIGA-CRC Human Imaging—now awarded her doctorate—University of Liège, Belgium. "In particular, the question of whether hypothalamus nuclei contribute to the stimulating impact of light on cognition is not established."

To better understand the impact of light on human cognition, Campbell and colleagues recruited 26 healthy young adults to participate in their study. They asked each participant to complete two auditory cognitive tasks; an executive task modified from the "n-back task" in which participants were asked to determine whether a current sound was identical to the one they heard two items earlier, or contained the letter "K"; and an emotional task, in which participants were asked to identify the gender of a voice that was either pronounced in a neutral tone or in an angry tone.

Each task was completed while the individuals were alternatively placed in darkness, or exposed to short periods of light in four levels of illumination. The team used a technique called 7 Tesla functional magnetic resonance imaging, which has a higher resolution and signal-to-noise ratio compared with standard 3 Tesla MRI, to assess the impact of the different light levels on the activity of the hypothalamus during the tasks.

The researchers found that during both tasks, higher levels of light triggered an increase in activity over the posterior hypothalamus. In contrast, the inferior and anterior hypothalamus followed a seemingly opposite pattern, exhibiting decreased activity under higher levels of light.

Next, the team sought to determine whether these changes in regional hypothalamus activity were related to a change in cognitive performance. They focused on assessing the participants' performance during the executive task, as this required a higher level of cognition to solve. Their analysis revealed that higher levels of light indeed led to better performance in the task, indicating an increase in cognitive performance.

Importantly, the increase in cognitive performance under higher illuminance was found to be significantly negatively correlated with the activity of the posterior hypothalamus. This makes it unlikely that the posterior hypothalamus activity directly mediates the positive impact of light on cognitive performance, and possibly hints at other brain regions being involved, requiring further research.

On the other hand, the activity of the posterior hypothalamus was found to be associated with an increased behavioral response to the emotional task. This suggests that the association between cognitive performance and the activity of the posterior hypothalamus may be context dependent—in some tasks, certain hypothalamus nuclei or neuronal populations may be recruited to increase performance, but not in others.

The authors call for future work in this area to assess the impact of light on other structures, or entire networks of the brain to determine how varying light levels modify their crosstalk and interactions with the cortex to bring about behavioral changes.

"The questions that remain from our study are important to answer, because acting on light stands as a promising easy to implement means to reduce fatigue throughout the day, improving cognitive defects and allowing a restful night's sleep with minimal cost and side effects," says Campbell.

"Our results demonstrate that the human hypothalamus does not respond uniformly to varying levels of light while engaged in a cognitive challenge," says senior author, Gilles Vandewalle, co-director of the GIGA-CRC Human Imaging, University of Liège. "Higher levels of light were found to be associated with higher cognitive performance, and our results indicate that this stimulating impact is mediated, in part, by the posterior hypothalamus. This region is likely to work jointly with the decreased activity of the anterior and inferior hypothalamus, along with other non-hypothalamus brain structures that regulate wakefulness."

"Targeted lighting for therapeutic use is an exciting prospect. However, it will require a more comprehensive understanding of how light affects the brain, particularly at the subcortical level. Our findings represent an important step towards this goal, at the level of the hypothalamus," notes Campbell.

More information: Islay Campbell et al, Regional response to light illuminance across the human hypothalamus, *eLife* (2024). DOI: 10.7554/eLife.96576.1

Provided by eLife

Researchers discover neural mechanism that encodes familiar faces

People experience a sense of familiarity from those who provide them with food and care on a daily basis. For children and pets, remembering the faces of such individuals is crucial for survival.

The basal ganglia, specifically the striatum tail, located in the deep region of the brain, plays a critical role in associating objects with their value through long-term experience. However, insight into how this mechanism operates in complex social situations, such as daily life, which is different from laboratory environments, remains unclear.

In this study, published in *iScience*, researchers from the University of Tsukuba presented monkeys with images of familiar and unfamiliar faces and recorded the neural activity from the tail part of the striatum. The neuronal mechanism used for storing the faces of familiar individuals in the brain was found to be the same as that used for remembering the value of objects.

The researchers showed the monkeys photographs of people who had cared for them daily for over a year as well as photographs of strangers, and recorded the neural activity from the tail part of the striatum.

The caudate nucleus responded strongly to familiar faces but weakly to unfamiliar ones. Moreover, the same neurons responded similarly to the varying values of objects. Considering that these neurons are also involved in rapid identification of valuable objects, they may be important in enabling children and pets to quickly identify familiar individuals.

These findings elucidate the mechanisms through which the brain forms and maintains social relationships. They are also useful in understanding and treating disorders caused by damage to the basal ganglia, including the tail part of the striatum, such as Parkinson's disease.

More information: Jun Kunimatsu et al, Neuronal response of the primate striatum tail to face of socially familiar persons, *iScience* (2024). DOI: 10.1016/j.isci.2024.110043

Provided by University of Tsukuba

Study suggests how brain, with sleep, learns meaningful maps of spaces

Place cells are well known to encode individual locations, but new experiments and analysis indicate that stitching together a "cognitive map" of a whole environment requires a broader ensemble of cells, aided by sleep, to build a richer network over several days.

On the first day of your vacation in a new city, your explorations expose you to innumerable individual places. While the memories of these spots (like a beautiful garden on a quiet side street) feel immediately indelible, it might be days before you have enough intuition about the neighborhood to direct a newer tourist to that same site and then maybe to the café you discovered nearby.

A new study in mice by MIT neuroscientists at The Picower Institute for Learning and Memory provides new evidence for how the brain forms cohesive cognitive maps of whole spaces and highlights the critical importance of sleep for the process.

Scientists have known for decades that the brain devotes neurons in a region called the hippocampus to remembering specific locations. So-called "place cells" reliably activate when an animal is at the location the neuron is tuned to remember. But more useful than having markers of specific spaces is having a mental model of how they all relate in a continuous overall geography. Though such "cognitive maps" were formally theorized in 1948, neuroscientists have remained unsure of how the brain constructs them.

The new study in the December edition of *Cell Reports* finds that the capability may depend upon subtle but meaningful changes over days in the activity of cells that are only weakly attuned to individual locations, but that increase the robustness and refinement of the hippocampus's encoding of the whole space. With sleep, the study's analyses indicate, these "weakly spatial" cells increasingly enrich neural network activity in the hippocampus to link together these places into a cognitive map.

"On day 1, the brain doesn't represent the space very well," said lead author Wei Guo, a research scientist in the lab of senior author Matthew Wilson, Sherman Fairchild Professor in The Picower Institute and MIT's Departments of Biology and Brain and Cognitive Sciences.

"Neurons represent individual locations, but together they don't form a map. But on day 5 they form a map. If you want a map, you need all these neurons to work together in a coordinated ensemble."

Mice mapping mazes

To conduct the study, Guo and Wilson along with labmates Jie "Jack" Zhang and Jonathan Newman introduced mice to simple mazes of varying shapes and let them explore them freely for about half an hour a day for several days. Importantly, the mice were not directed to learn anything specific through the offer of any rewards. They just wandered. Previous studies have shown that mice naturally demonstrate "latent learning" of spaces from this kind of unrewarded experience after several days.

To understand how latent learning takes hold, Guo and his colleagues visually monitored hundreds of neurons in the CA1 area of the hippocampus by engineering cells to flash when a buildup of calcium ions made them electrically active. They not only recorded the neurons' flashes when the mice were actively exploring, but also while they were sleeping. Wilson's lab has shown that animals "replay" their previous journeys during sleep, essentially refining their memories by dreaming about their experiences.

Analysis of the recordings showed that the activity of the place cells developed immediately and remained strong and unchanged over several days of exploration. But this activity alone wouldn't explain how latent learning or a cognitive map evolves over several days.

So unlike in many other studies where scientists focus solely on the strong and clear activity of place cells, Guo extended his analysis to the more subtle and mysterious activity of cells that were not so strongly spatially tuned. Using an emerging technique called "manifold learning" he was able to discern that many of the "weakly spatial" cells gradually correlated their activity not with locations, but with activity patterns among other neurons in the network. As this was happening, Guo's analyses showed, the network encoded a cognitive map of the maze that increasingly resembled the literal, physical space.

"Although not responding to specific locations like strongly spatial cells, weakly spatial cells specialize in responding to ''mental locations,"' i.e., specific ensemble firing patterns of other cells," the study authors wrote. "If a weakly spatial cell's mental field encompasses two subsets of strongly spatial cells that encode distinct locations, this weakly spatial cell can serve as a bridge between these locations."

In other words, the activity of the weakly spatial cells likely stitches together the individual locations represented by the place cells into a mental map.

The need for sleep

Studies by Wilson's lab and many others have shown that memories are consolidated, refined and processed by neural activity, such as replay, that occurs during sleep and rest. Guo and Wilson's team therefore sought to test whether sleep was necessary for the contribution of weakly spatial cells to latent learning of cognitive maps.

To do this they let some mice explore a new maze twice during the same day with a three-hour siesta in between. Some of the mice were allowed to sleep but some were not. The ones that did showed a significant refinement of their mental map, but the ones that weren't allowed to sleep showed no such improvement.

Not only did the network encoding of the map improve, but also measures of the tuning of individual cells during showed that sleep helped cells become better attuned both to places and to patterns of network activity, so called "mental places" or "fields."

Mental map meaning

The "cognitive maps" the mice encoded over several days were not literal, precise maps of the mazes, Guo notes. Instead they were more like schematics. Their value is that they provide the brain with a topology that can be explored mentally, without having to be in the physical space.

For instance, once you've formed your cognitive map of the neighborhood around your hotel, you can plan the next morning's excursion (e.g. you could imagine grabbing a croissant at the bakery you observed a few blocks west and then picture eating it on one of those benches you noticed in the park along the river).

Indeed, Wilson hypothesized that the weakly spatial cells' activity may be overlaying salient non-spatial information that brings additional meaning to the maps (i.e. the idea of a bakery is not spatial, even if it's closely linked to a specific location). The study, however, included no landmarks within the mazes and did not test any specific behaviors among the mice.

But now that the study has identified that weakly spatial cells contribute meaningfully to mapping, Wilson said future studies can investigate what kind of information they may be incorporating into the animals' sense of their environments. We seem to intuitively regard the spaces we inhabit as more than just sets of discrete locations.

"In this study we focused on animals behaving naturally and demonstrated that during freely exploratory behavior and subsequent sleep, in the absence of reinforcement, substantial neural plastic changes at the ensemble level still occur," the authors concluded. "This form of implicit and unsupervised learning constitutes a crucial facet of human learning and intelligence, warranting further in-depth investigations."

More information: Wei Guo et al, Latent learning drives sleep-dependent plasticity in distinct CA1 subpopulations, *Cell Reports* (2024). DOI: 10.1016/j.celrep.2024.115028

Provided by Massachusetts Institute of Technology

Researchers discovered the part of the brain that controls memory and information recall

The claustrum complex, a small yet powerful region in the brain, has intrigued scientists for years. Found across mammalian species, reptiles, and birds, this conserved brain structure is believed to play a pivotal role in higher-order cognitive functions.

With extensive connections across both cortical and subcortical areas, the claustrum coordinates neural activity on a global scale. This interconnectivity links the claustrum to various cognitive functions such as sensory perception and attention, which in turn affect processes like working, associative, and recognition memory.

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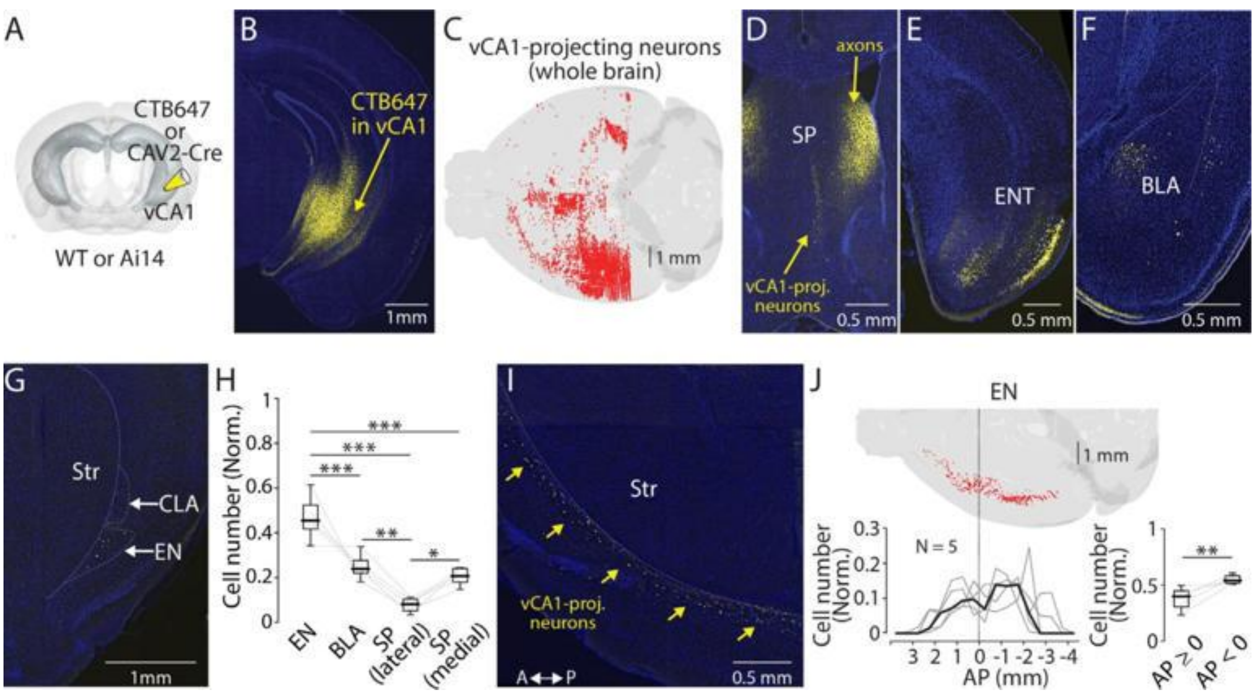
the claustrum to various cognitive functions such as sensory perception and attention, which in turn affect processes like working, associative, and recognition memory.

Abnormalities within the claustrum are also linked to cognitive disorders, including Alzheimer's disease, schizophrenia, and attention-deficit/hyperactivity disorder (ADHD).

Researchers have long speculated on the microstructure and unique functions within this brain region, but the exact workings remained unclear. Now, a groundbreaking study from Aarhus University has shed new light on one of its subregions: the endopiriform nucleus (EN). This discovery offers a deeper look into how specific neurons within the EN contribute to recognition memory, offering insights that may eventually help in treating cognitive disorders.



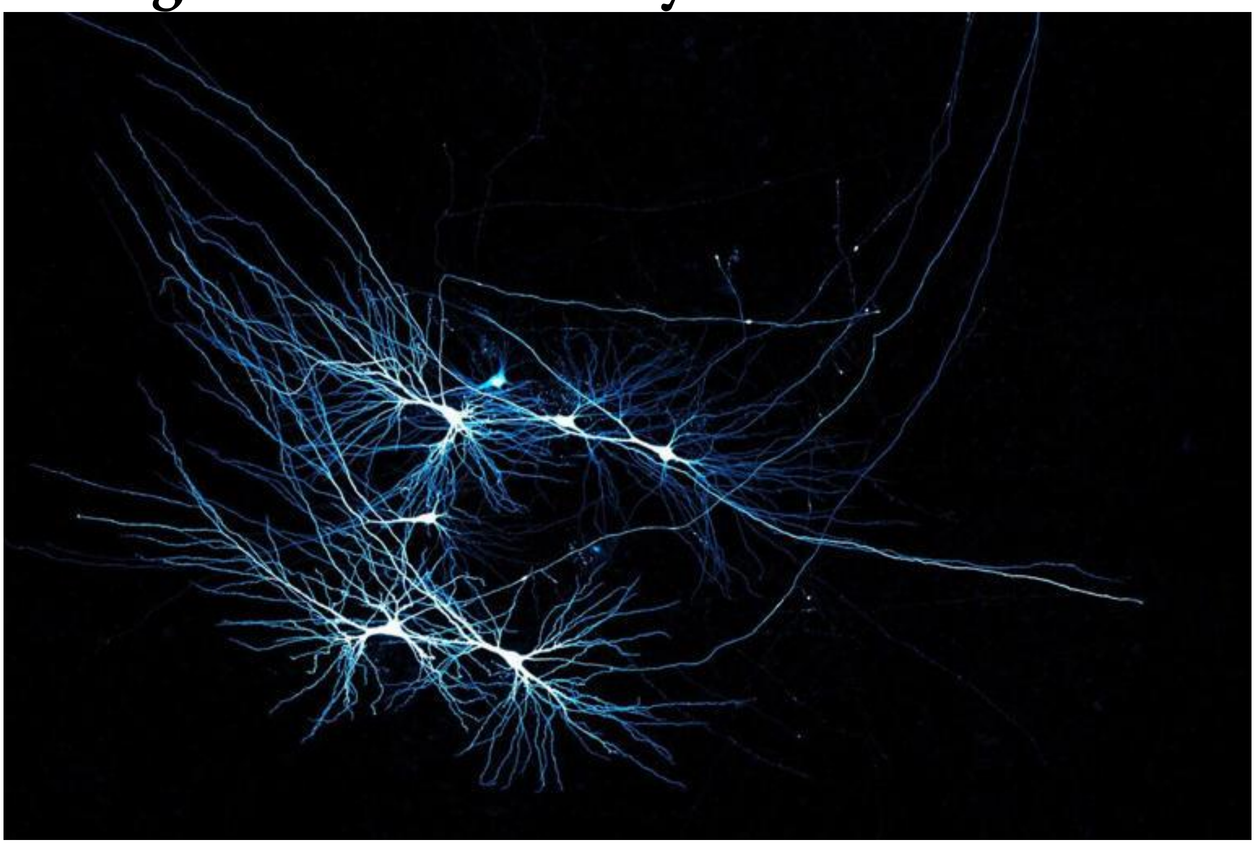
Schematic diagram of a retrograde tracer injection performed. CAV-2-Cre or CTB647 was used in combination with Ai14 or wild-type mice, respectively. (CREDIT: eLife)© The Brighter Side of News

The claustrum complex is divided into two parts based on its cellular structure and genetic expression: the dorsal region, known simply as the "claustrum," and the ventral region, or the "endopiriform nucleus." The dorsal claustrum connects broadly with sensory, motor, and association areas in the cortex, producing different physiological effects depending on its target areas.

In contrast, the EN forms connections with the piriform cortex, which processes olfactory information, and the limbic system, which is critical for memory and emotional processing. This division suggests that each part of the claustrum has a distinct role in organizing and transmitting information.

One of the primary functions of the endopiriform nucleus is its connection to the ventral CA1 (vCA1) region of the hippocampus, a brain area known to regulate behaviors associated with exploration and recognition memory. Based on this connection, researchers hypothesized that the EN is a key node for establishing recognition memory. To explore this, they used advanced genetic tools and mouse models, focusing on a specific group of EN neurons that project directly to the vCA1, dubbed "EN vCA1-proj. neurons."

Neurosurgeons unravel the distinct nerve wiring of human memory



Human CA3 pyramidal neurons recorded in a patient tissue sample. Credit: Jake Watson

The black box of the human brain is starting to open. Although animal models are instrumental in shaping our understanding of the mammalian brain, scarce human data is uncovering important specificities.

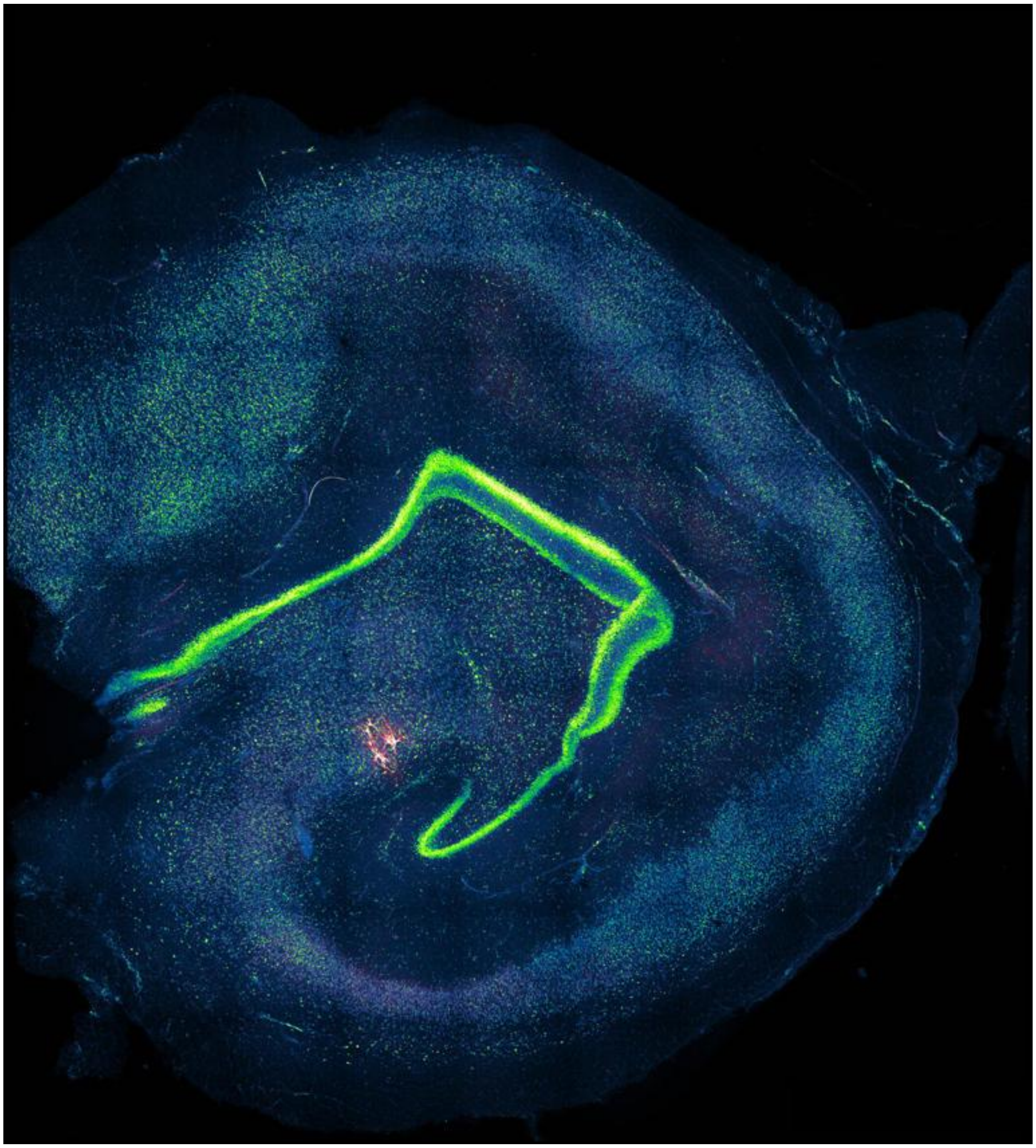
In a paper published in *Cell*, a team led by the Jonas group at the Institute of Science and Technology Austria (ISTA) and neurosurgeons from the Medical University of Vienna shed light on the human hippocampal CA3 region, central for memory storage.

Many of us have relished those stolen moments with a grandparent by the fireplace, our hearts racing to the intrigues of their stories from good old times, recounted with vivid imagery and a pinch of fantasy.

Our human brain has a remarkable capacity for storing and recollecting memories over a lifetime. A physical space, a smell, or a familiar situation can alone bring back a memory, and our brain uses these associations to complete the pattern.

Although the human brain is optimized for this purpose, we are only starting to understand how it integrates information about our surroundings. This pattern-completion process is a remarkable computational property of our brain called associative memory.

The bulk of our neuroscience knowledge about the brain stems from well-studied animal models, like rodents, which are indispensable for science. But is the human brain simply a scaled-up version of the mouse brain, or does it have distinct features that make it human?

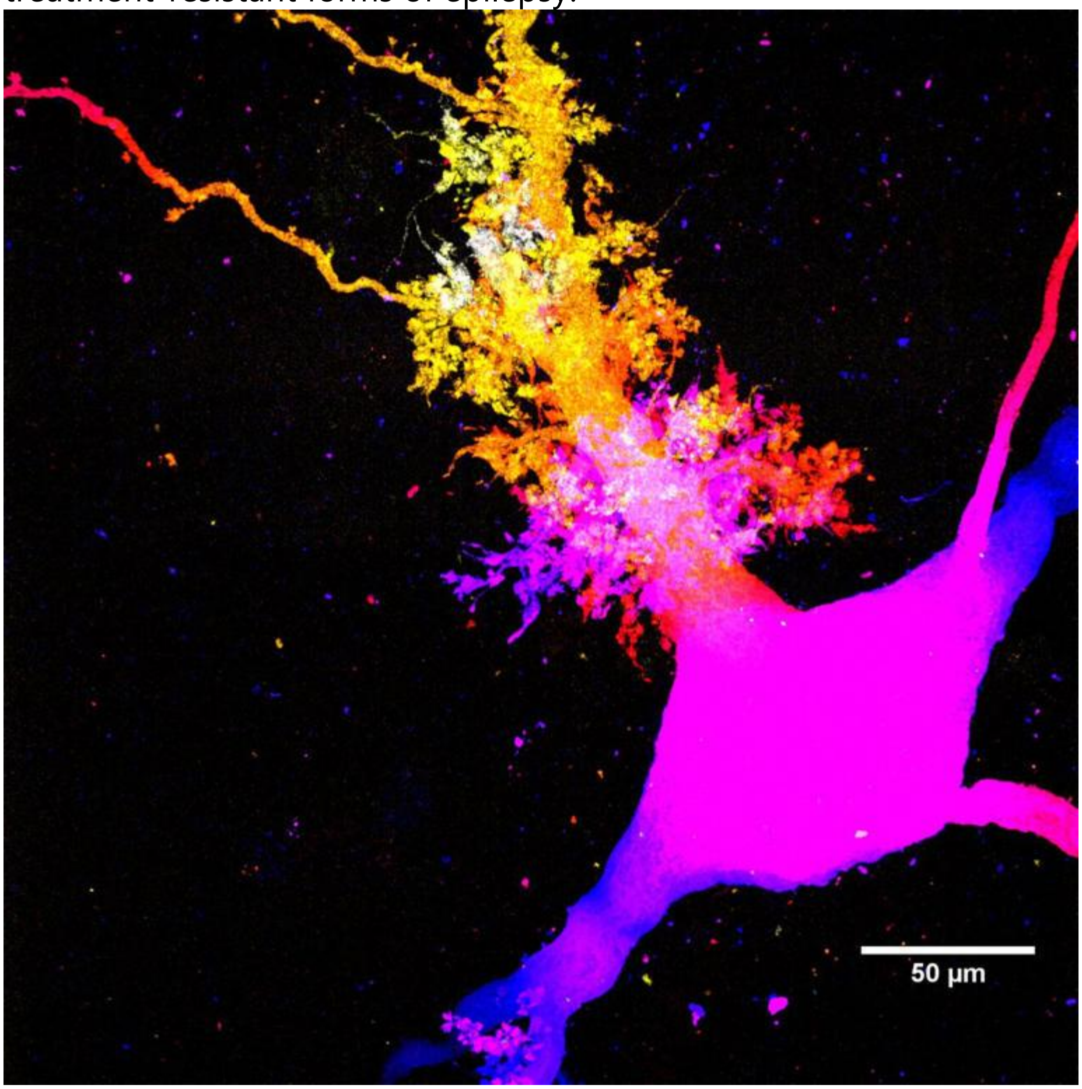

Multicellular recorded CA3 neurons (red), in human hippocampal tissue slice (green/blue). Credit: Jake Watson

Now, researchers at the Institute of Science and Technology Austria (ISTA) and neurosurgeons at the Medical University of Vienna shed light on how the human brain forms and retrieves associative memories.

Magdalena Walz, Professor of Life Sciences at ISTA Peter Jonas and ISTA postdoc Jake Watson, who initiated the collaboration with Professor Karl Rössler from the Department of Neurosurgery of the Medical University of Vienna, examined samples from epilepsy patients who underwent neurosurgery to gain insights directly from intact, living human tissue.

Humans do not have a 'big mouse brain'

The brain's center for learning and associative memory is the hippocampus. Within it, a region called CA3 is responsible for storing and processing information and completing patterns. Because healthy human material is scarce, most studies have so far focused on animal models. Jonas and Watson overcame this problem by teaming up with Rössler, a neurosurgeon specializing in treatment-resistant forms of epilepsy.



Postsynaptic structures on a human hippocampal neuron from patient tissue. Credit: Jake Watson

"While patients undergoing neurosurgery have a wide variety of clinical presentations, Prof. Rössler identified a subpopulation of epilepsy patients who presented an intact hippocampus," says Jonas. The scientists could not possibly miss this opportunity.

"In this form of epilepsy, a unilateral resection of the hippocampus is necessary to ensure the patients have a chance to recover and lead an epilepsy-free life," explains Jonas. Thus, the team could obtain intact hippocampal tissue from 17 epilepsy patients with informed consent. The researchers combined cutting-edge experimental techniques—multicellular patch-clamp recording to measure dynamic functional properties of neurons and super-resolution microscopy—with modeling and made eye-opening findings.

Far from being a scaled-up version of the well-studied mouse hippocampus, the neural connectivity in the human CA3 region was sparser, and its synapses—the connections that allow signals to be passed between the neurons—appeared more reliable and precise. Thus, the team uncovered distinct properties of the human brain's wiring.

'It felt like we didn't know a thing'

Despite the important differences in the cellular structure and synaptic connectivity of the human hippocampus compared to that of mice and rats, data from animal models remains very important. It serves as a reference and helps scientists develop the technology for studying human tissue.

"Coming from a background working with rodents, it can feel like everything about the hippocampus is already known," says Watson.

"As soon as I started examining the first patient samples, I realized how much we didn't know about the human hippocampus. Although this is the best-studied brain region in rodents, it felt like we didn't know a thing about human physiology, cellular organization, or connectivity."

Thus, based on their experience working with rodent hippocampal tissue, Watson and Jonas needed to find new ways to re-examine this part of the brain in humans.

"Prof. Rössler is very keen on promoting basic research and has developed sophisticated techniques to extract patient tissue in the best possible condition for laboratory examination," emphasizes Watson.

This collaboration has given the ISTA researchers access to a scarce resource in science: intact, living human brain tissue. Since tissue availability depended on the surgeries, the scientists only received new biological material sporadically every few months.

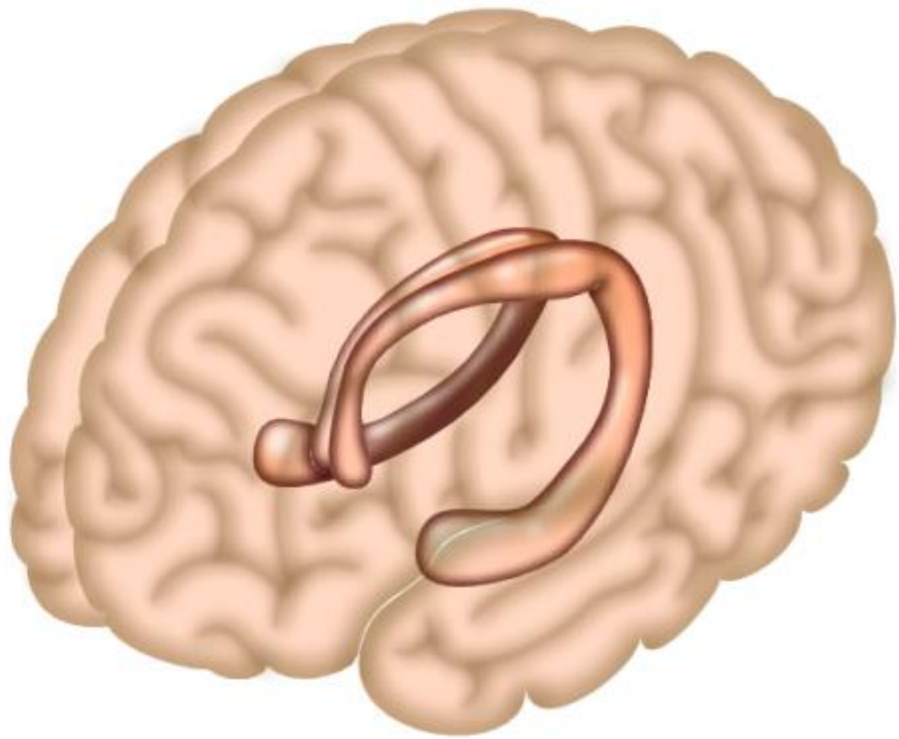
This has impacted their lab's logistics: they often needed to interrupt all projects using non-human material on short notice and clear the space to receive and examine the fresh human samples.

"It felt surreal thinking that the epilepsy patient who underwent neurosurgery the same morning was recovering in hospital while we were examining an intact and living slice of tissue from their brain," says Watson.

More information: Human hippocampal CA3 uses specific functional connectivity rules for efficient associative memory, *Cell* (2024). DOI: 10.1016/j.cell.2024.11.022. www.cell.com/cell/fulltext/S0092-8674(24)01338-2

Provided by Institute of Science and Technology Austria

Researchers uncover unexpected role of hippocampus in skilled movement control



The hippocampus is a region of the brain largely responsible for memory formation. Credit: Salk Institute

Researchers at the University of Birmingham have uncovered a surprising role of the hippocampus—linking this part of the brain to the control of skilled actions such as handwriting, typing, and playing music.

The hippocampus is traditionally associated with memory for events and spatial navigation, but a new study challenges these long-held distinctions and opens new possibilities for rehabilitation of neurological and neurodegenerative disorders that affect movement.

Publishing their findings in *The Journal of Neuroscience*, the research team reveal evidence suggesting that the hippocampus plays a role in retrieving and organizing flexible movement sequences from memory.

The research team reanalyzed functional MRI (fMRI) data to focus on brain activity in key subcortical regions as participants performed well-practiced finger sequences from memory on a force-sensitive keyboard, resembling piano playing.

While motor areas in the basal ganglia and the cerebellum—typically associated with the development of "muscle memory" for learned motor skills—showed increased activity during the sequence task, the study uncovered that it was the hippocampus, rather than these motor areas, that held information about the finger order of the sequence a participant was about to perform. This is like predicting whether a person would type "fears" or "fares" from the activity in the hippocampus alone.

Associate Professor and senior author of the study, Dr. Katja Kornysheva, from the University of Birmingham, commented, "This result is interesting because it shows that the brain systems for episodic and procedural memory work together more than we thought. This is especially true when we need to remain flexible and switch between learned sequences, for example, when typing on a computer keyboard or playing music with others."

Dr. Rhys Yewbrey, a former doctoral student in Kornysheva's research group and first author of the study added, "Our research suggests that the hippocampus may be important in skilled and flexible motor control, for setting up a course plan of action. This knowledge could help develop more effective training programs for neurological rehabilitation of actions, as well as for speeding up the acquisition of new skills."

The researchers hope their findings will encourage further exploration into the interaction between memory systems and inspire novel therapies that can enhance both motor function and cognitive health.

More information: Rhys Yewbrey et al, The hippocampus pre-orders movements for skilled action sequences, *The Journal of Neuroscience* (2024). DOI: 10.1523/JNEUROSCI.0832-24.2024

Provided by University of Birmingham

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

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

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

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

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

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

Researchers focused on visual learning in their study

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

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

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

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

Learning without any conscious awareness

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

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

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

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

Potential applications

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

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

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

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

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

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

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

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

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

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

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

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

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

Quantum secrets

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

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

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

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

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

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

Magical magnons

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

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

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

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

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

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

Why Our Brains Love Immersive Art.

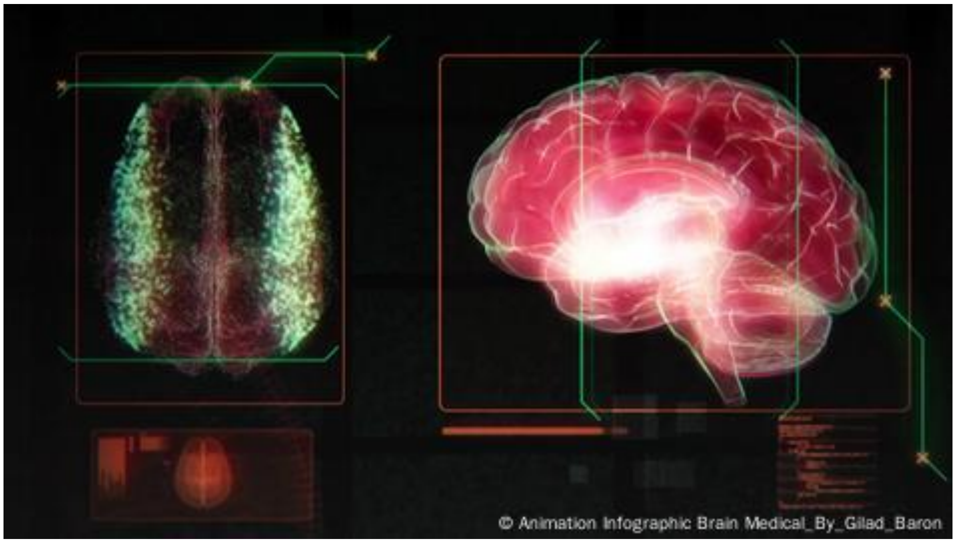
01/26/2024January 26, 2024

Immersive art is booming. What's behind the hype surrounding these colorful exhibitions? How effective are these installations? And do they heighten our appreciation of art?

Unpacking the success of immersive art. Exhibitions by the art collective teamLab are a smash hit. The interactive, walkable installations allow visitors to become part of the works. What makes this art form so effective?

Immersive exhibitions: repackaging famous works. Art curators are transforming classic paintings by renowned artists such as Van Gogh, Monet, and Kahlo into huge video installations. Some critics disapprove of these installations, while many visitors are fans.

Hypnotic digital data sculptures. Refik Anadol creates immersive and ever-changing art from data – with the help of artificial intelligence. It has made him one of the most popular media artists in the world.

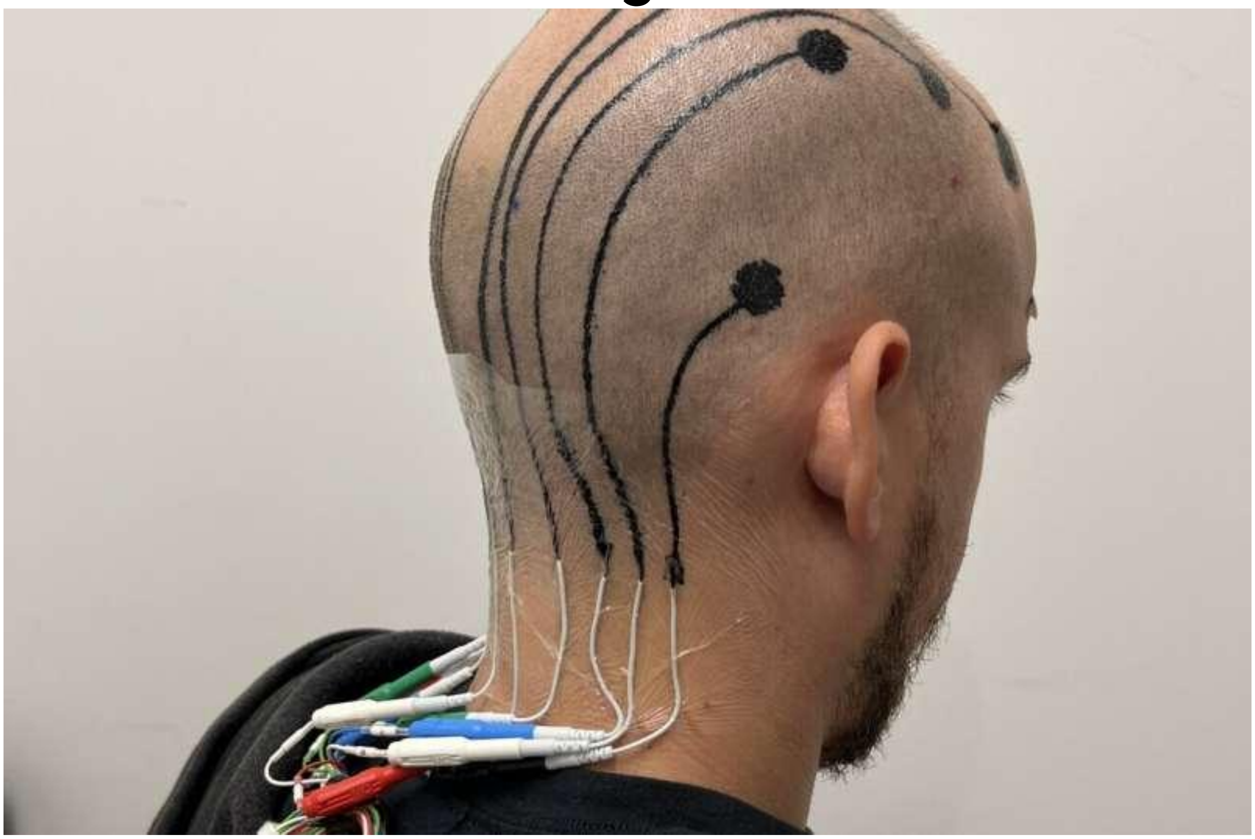


Why the brain loves immersive art. Scientists know why people are so enthusiastic about immersive art. For neuroaesthetics expert Susan Magsamen, one thing is clear: Art is as important for our well-being as a good night's sleep and exercise.

'Electronic' scalp tattoos could be next big thing in brain monitoring

DECEMBER 2, 2024

Temporary tattoo printed directly on the scalp offers easy, hair-friendly solution for measuring brainwaves



EEG setup with e-tattoo electrodes. Credit: Nanshu Lu

For the first time, scientists have invented a liquid ink that doctors can print onto a patient's scalp to measure brain activity. The technology, presented December 2 in the journal *Cell Biomaterials*, offers a promising alternative to the cumbersome process currently used for monitoring brainwaves and diagnosing neurological conditions. It also has the potential to enhance non-invasive brain-computer interface applications.

"Our innovations in sensor design, biocompatible ink, and high-speed printing pave the way for future on-body manufacturing of electronic tattoo sensors, with broad applications both within and beyond clinical settings," says Nanshu Lu, the paper's co-corresponding author at the University of Texas at Austin.

Electroencephalography (EEG) is an important tool for diagnosing a variety of neurological conditions, including seizures, brain tumors, epilepsy, and brain injuries. During a traditional EEG test, technicians measure the patient's scalp with rulers and pencils, marking over a dozen spots where they will glue on electrodes, which are connected to a data-collection machine via long wires to monitor the patient's brain activity. This setup is time-consuming and cumbersome, and it can be uncomfortable for many patients, who must sit through the EEG test for hours.

Lu and her team have been pioneering the development of small sensors that track bodily signals from the surface of human skin, a technology known as electronic tattoos, or e-tattoos. Scientists have applied e-tattoos to the chest to measure heart activities, on muscles to measure how fatigued they are, and even under the armpit to measure components of sweat.

In the past, e-tattoos were usually printed on a thin layer of adhesive material before being transferred onto the skin, but this was only effective on hairless areas.

"Designing materials that are compatible with hairy skin has been a persistent challenge in e-tattoo technology," Lu says.

To overcome this, the team designed a type of liquid ink made of conductive polymers. The ink can flow through hair to reach the scalp, and once dried, it works as a thin-film sensor, picking up brain activity through the scalp.

Using a computer algorithm, the researchers can design the spots for EEG electrodes on the patient's scalp. Then, they use a digitally controlled inkjet printer to spray a thin layer of the e-tattoo ink on to the spots. The process is quick, requires no contact, and causes no discomfort in patients, the researchers said.

The team printed e-tattoo electrodes onto the scalps of five participants with short hair. They also attached conventional EEG electrodes next to the e-tattoos. The team found that the e-tattoos performed comparably well at detecting brainwaves with minimal noise.

After six hours, the gel on the conventional electrodes started to dry out. Over a third of these electrodes failed to pick up any signal, although most the remaining electrodes had reduced contact with the skin, resulting in less accurate signal detection. The e-tattoo electrodes, on the other hand, showed stable connectivity for at least 24 hours.

Additionally, researchers tweaked the ink's formula and printed e-tattoo lines that run down to the base of the head from the electrodes to replace the wires used in a standard EEG test.

"This tweak allowed the printed wires to conduct signals without picking up new signals along the way," says co-corresponding author Ximin He of the University of California, Los Angeles.

The team then attached much shorter physical wires between the tattoos to a small device that collects brainwave data. The team said that in the future, they plan to embed wireless data transmitters in the e-tattoos to achieve a fully wireless EEG process.

"Our study can potentially revolutionize the way non-invasive brain-computer interface devices are designed," says co-

corresponding author José Millán of the University of Texas at Austin.

Brain-computer interface devices work by recording brain activities associated with a function, such as speech or movement, and use them to control an external device without having to move a muscle.

Currently, these devices often involve a large headset that is cumbersome to use. E-tattoos have the potential to replace the external device and print the electronics directly onto a patient's head, making brain-computer interface technology more accessible, Millán says.

More information: Luize Scalco de Vasconcelos et al. On-Scalp Printing of Personalized Electroencephalography E-Tattoos, *Cell Biomaterials* (2024). DOI:

10.1016/j.celbio.2024.100004. www.cell.com/cell-biomaterials … 3050-5623(24)00004-7

Noninvasive imaging method can penetrate deeper into living tissue

The new technique enables laser light to penetrate deeper into living tissue, which captures sharper images of cells at different layers of a living system. On left is the initial image, and on right is the optimized image using the new technique. Credit: Sixian You et al

Metabolic imaging is a noninvasive method that enables clinicians and scientists to study living cells using laser light, which can help them assess disease progression and treatment responses.

But light scatters when it shines into biological tissue, limiting how deep it can penetrate and hampering the resolution of captured images.

Now, MIT researchers have developed a new technique that more than doubles the usual depth limit of metabolic imaging. Their method also boosts imaging speeds, yielding richer and more detailed images.

This new technique does not require tissue to be preprocessed, such as by cutting it or staining it with dyes. Instead, a specialized laser illuminates deep into the tissue, causing certain intrinsic molecules within the cells and tissues to emit light. This eliminates the need to alter the tissue, providing a more natural and accurate representation of its structure and function.

The researchers achieved this by adaptively customizing the laser light for deep tissues. Using a recently developed fiber shaper—a device they control by bending it—they can tune the color and pulses of light to minimize scattering and maximize the signal as the light travels deeper into the tissue. This allows them to see much further into living tissue and capture clearer images.

Greater penetration depth, faster speeds, and higher resolution make this method particularly well-suited for demanding imaging applications like cancer research, tissue engineering, drug discovery, and the study of immune responses.

"This work shows a significant improvement in terms of depth penetration for label-free metabolic imaging. It opens new avenues for studying and exploring metabolic dynamics deep in living biosystems," says Sixian You, assistant professor in the Department of Electrical Engineering and Computer Science (EECS), a member of the Research Laboratory for Electronics, and senior author of a paper on this imaging technique.

She is joined on the paper by lead author Kunzan Liu, an EECS graduate student; Tong Qiu, an MIT postdoc; Honghao Cao, an EECS graduate student; Fan Wang, professor of brain and cognitive sciences; Roger Kamm, the Cecil and Ida Green Distinguished Professor of Biological and Mechanical Engineering; Linda Griffith, the School of Engineering Professor of Teaching Innovation in the Department of Biological Engineering; and other MIT colleagues.

The research appears in *Science Advances*.

Laser-focused

This new method falls in the category of label-free imaging, which means tissue is not stained beforehand. Staining creates contrast that helps a clinical biologist see cell nuclei and proteins better. But staining typically requires the biologist to section and slice the sample, a process that often kills the tissue and makes it impossible to study dynamic processes in living cells.

In label-free imaging techniques, researchers use lasers to illuminate specific molecules within cells, causing them to emit light of different colors that reveal various molecular contents and cellular structures. However, generating the ideal laser light with certain wavelengths and high-quality pulses for deep-tissue imaging has been challenging.

The researchers developed a new approach to overcome this limitation. They use a multimode fiber, a type of optical fiber which can carry a significant amount of power, and could couple it with a compact device called a "fiber shaper." This shaper allows them to precisely modulate the light propagation by adaptively changing the shape of the fiber. Bending the fiber changes the color and intensity of the laser.

Building on prior work, the researchers adapted the first version of the fiber shaper for deeper multimodal metabolic imaging.

"We want to channel all this energy into the colors we need with the pulse properties we require. This gives us higher generation efficiency and a clearer image, even deep within tissues," says Cao.

Once they had built the controllable mechanism, they developed an imaging platform to leverage the powerful laser source to generate longer wavelengths of light, which are crucial for deeper penetration into biological tissues.

"We believe this technology has the potential to significantly advance biological research. By making it affordable and accessible to biology labs, we hope to empower scientists with a powerful tool for discovery," Liu says.

Dynamic applications

When the researchers tested their imaging device, the light was able to penetrate more than 700 micrometers into a biological sample, whereas the best prior techniques could only reach about 200 micrometers.

"With this new type of deep imaging, we want to look at biological samples and see something we have never seen before," Liu adds.

The deep imaging technique enabled them to see cells at multiple levels within a living system, which could help researchers study metabolic changes that happen at different depths. In addition, the faster imaging speed allows them to gather more detailed information on how a cell's metabolism affects the speed and direction of its movements.

This new imaging method could offer a boost to the study of organoids, which are engineered cells that can grow to mimic the structure and function of organs. Researchers in the Kamm and Griffith labs pioneer the development of brain and endometrial organoids that can grow like organs for disease and treatment assessment.

However, it has been challenging to precisely observe internal developments without cutting or staining the tissue, which kills the sample.

This new imaging technique allows researchers to noninvasively monitor the metabolic states inside a living organoid while it continues to grow.

With these and other biomedical applications in mind, the researchers plan to aim for even higher-resolution images. At the same time, they are working to create low-noise laser sources, which could enable deeper imaging with less light dosage.

They are also developing algorithms that react to the images to reconstruct the full 3D structures of biological samples in high resolution.

In the long run, they hope to apply this technique in the real world to help biologists monitor drug response in real-time to aid in the development of new medicines.

"By enabling multimodal metabolic imaging that reaches deeper into tissues, we're providing scientists with an unprecedented ability to observe nontransparent biological systems in their natural state. We're excited to collaborate with clinicians, biologists, and bioengineers to push the boundaries of this technology and turn these insights into real-world medical breakthroughs," You says.

More information: Kunzan Liu et al, Deep and Dynamic Metabolic and Structural Imaging in Living Tissues, *Science Advances* (2024). DOI: 10.1126/sciadv.adp2438. www.science.org/doi/10.1126/sciadv.adp2438

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Provided by Massachusetts Institute of Technology

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

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

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

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

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

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

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

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

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

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

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

Australian breakthrough: New smartphone battery could triple lifespan

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

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

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

Are we on the brink of a smartphone battery revolution?

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

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

How long will the new battery last?

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

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

Transparent phones: The future of smartphones unveiled

The transparent phone has emerged as one of the most innovative solutions in the technology industry, capturing the interest of both tech enthusiasts and designers seeking new inspiration. What possibilities does this groundbreaking invention offer, and could it become a permanent fixture in the market?

Is it possible to use a transparent phone?
Images source: © Getty Images | Devrimb
KAW
10:48 AM EDT, October 10, 2024
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Not long ago, the transparent phone was associated solely with futuristic visions in science fiction movies. Technological advancements like OLED and microLED screens are turning this idea into reality. Companies like Xiaomi are experimenting with **transparent device prototypes to revolutionize the market**. Although significant progress is needed before the full implementation of such phones, their advantages and limitations are garnering more interest.

The transparent phone - an excellent example of innovative technology

The transparent phone once seemed like a distant dream from science fiction films. However, **this concept has become a reality thanks to rapid advances in screen technology**

and component miniaturization. **Transparent smartphones are designed to be see-through**, offering entirely new ways to interact with the device.

By utilizing transparent materials and innovative technologies such as **OLED** or **microLED screens**, **transparent phones can deliver high-quality images while maintaining their see-through quality**. This groundbreaking development is also enabled by the advancement of components concealed in narrow frames or specific sections, creating "invisible" electronic circuits. Tech companies like **Samsung** and **Xiaomi** are actively researching this solution, suggesting it may become a relatively widespread technology.

How to use a transparent phone?

The market currently has limited options for transparent phones. However, in recent years, several companies have showcased **prototypes** or announced their development efforts in this area. Among the most notable examples are the Samsung Galaxy and the **Xiaomi Mi MIX Alpha** model, which, while not entirely transparent, represents a step toward modern screens that occupy almost the entire phone surface. **Transparency technology** offers more intuitive operation, allowing users to **browse content on both the front and back of the device**.

Using a transparent phone may differ from using conventional devices. Transparent screens with touch interfaces enable fresh interaction. Additionally, with more dynamic content display capability, the **user can adjust the display's transparency** according to current needs. For instance, they might dim it while typing a message or increase transparency for a more futuristic effect. Although this technology needs further refinement, future models are anticipated to become **more functional and affordable**.

Pros and cons of the transparent phone

The advantages of a transparent phone primarily include its modern design and unique capabilities. With a transparent screen, the device stands out from traditional smartphones and attracts attention with its unconventional appearance. **Transparency can also enhance the intuitiveness of operation**, enabling users to utilize both sides of the phone to display information and manage content.

However, transparent phones also have their drawbacks. One of the main challenges is reduced battery capacity. Placing components in narrow frames means smaller batteries, which can impact the device's usage time. Another concern is the **limited durability of the construction**, as transparent materials tend to be more susceptible to damage than traditional casings. Repairing such a phone could also be costly and challenging due to its complex structure.

It's also worth mentioning the price – **producing transparent phones involves high costs**, making them accessible to only a select group of users. Nevertheless, this technology may find wider application in the future as production costs decrease and functionality improves.

New evidence for a human magnetic sense that lets your brain detect the Earth's magnetic field

Published: March 18, 2019 1:01pm EDT

Do you have a magnetic compass in your head? Lightspring/Shutterstock.com

Do human beings have a magnetic sense? Biologists know other animals do. They think it helps creatures including bees, turtles and birds navigate through the world.

Scientists have tried to investigate whether humans belong on the list of magnetically sensitive organisms. For decades, there's been a back-and-forth between positive reports and failures to demonstrate the trait in people, with seemingly endless controversy.

The mixed results in people may be due to the fact that virtually all past studies relied on behavioral decisions from the participants. If human beings do possess a magnetic sense, daily experience suggests that it would be very weak or deeply subconscious. Such faint impressions could easily be misinterpreted – or just plain missed – when trying to make decisions.

So our research group – including a geophysical biologist, a cognitive neuroscientist and a neuroengineer – took another approach. What we found arguably provides the first concrete neuroscientific evidence that humans do have a geomagnetic sense.

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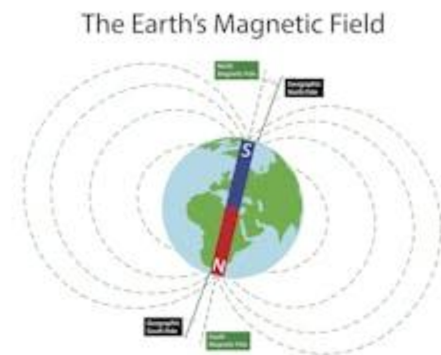
How does a biological geomagnetic sense work?

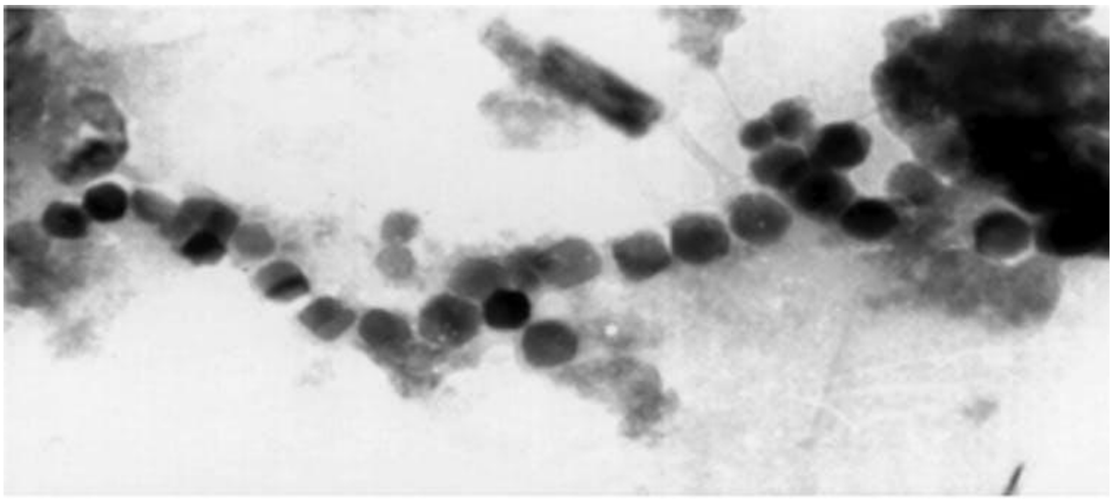


Life on Earth is exposed to the planet's ever-present geomagnetic field that varies in intensity and direction across the planetary surface. Nasky/Shutterstock.com

The Earth is surrounded by a magnetic field, generated by the movement of the planet's liquid core. It's why a magnetic compass points north. At Earth's surface, this magnetic field is fairly weak, about 100 times weaker than that of a refrigerator magnet.

Over the past 50 years or so, scientists have shown that hundreds of organisms in nearly all branches of the bacterial, protist and animal kingdoms have the ability to detect and respond to this geomagnetic field. In some animals – such as honey bees – the geomagnetic behavioral responses are as strong as the responses to light, odor or touch. Biologists have identified strong responses in vertebrates ranging from fish, amphibians, reptiles, numerous birds and a diverse variety of mammals including whales, rodents, bats, cows and dogs – the last of which can be trained to find a hidden bar magnet. In all of these cases, the animals are using the geomagnetic field as components of their homing and navigation abilities, along with other cues like sight, smell and hearing.

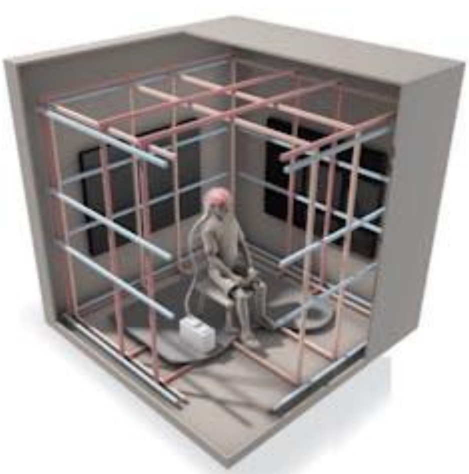
Skeptics dismissed early reports of these responses, largely because there didn't seem to be a biophysical mechanism that could translate the Earth's weak geomagnetic field into strong neural signals. This view was dramatically changed by the discovery that living cells have the ability to build nanocrystals of the ferromagnetic mineral magnetite – basically, tiny iron magnets. Biogenic crystals of magnetite were first seen in the teeth of one group of mollusks, later in bacteria, and then in a variety of other organisms ranging from protists and animals such as insects, fish and mammals, including within tissues of the human brain.



Chains of magnetosomes from a sockeye salmon. Mann, Sparks, Walker & Kirschvink, 1988, CC BY-ND

Nevertheless, scientists haven't considered humans to be magnetically sensitive organisms.

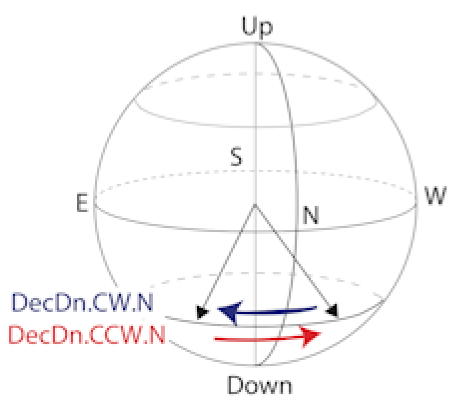
Manipulating the magnetic field



Schematic drawing of the human magnetoreception test chamber at Caltech. Modified from 'Center of attraction' by C. Bickel (Hand, 2016).

In our new study, we asked 34 participants simply to sit in our testing chamber while we directly recorded electrical activity in their brains with electroencephalography (EEG). Our modified Faraday cage included a set of 3-axis coils that let us create controlled magnetic fields of high uniformity via electric current we ran through its wires. Since we live in mid-latitudes of the Northern Hemisphere, the environmental magnetic field in our lab dips downwards to the north at about 60 degrees from horizontal.

In normal life, when someone rotates their head – say, nodding up and down or turning the head from left to right – the direction of the geomagnetic field (which remains constant in space) will shift relative to their skull. This is no surprise to the subject's brain, as it directed the muscles to move the head in the appropriate fashion in the first place.



Study participants sat in the experimental chamber facing north, while the downwards-pointing field rotated clockwise (blue arrow) from northwest to northeast or counterclockwise (red arrow) from northeast to northwest. Magnetic Field Laboratory, Caltech, CC BY-ND

In our experimental chamber, we can move the magnetic field silently relative to the brain, but without the brain having initiated any signal to move the head. This is comparable to situations when your head or trunk is passively rotated by somebody else, or when you're a passenger in a vehicle which rotates. In those cases, though, your body will still register vestibular signals about its position in space, along with the magnetic field changes – in contrast, our experimental stimulation was only a magnetic field shift. When we shifted the magnetic field in the chamber, our participants did not experience any obvious feelings.

The EEG data, on the other hand, revealed that certain magnetic field rotations could trigger strong and reproducible brain responses. One EEG pattern known from existing research, called alpha-ERD (event-related desynchronization), typically shows up when a person suddenly detects and processes a sensory stimulus. The brains were "concerned" with the unexpected change in the magnetic field direction, and this triggered the alpha-wave reduction. That we saw such alpha-ERD patterns in response to simple magnetic rotations is powerful evidence for human magnetoreception.

Video shows the dramatic, widespread drop in alpha wave amplitude (deep blue color on leftmost head) following counterclockwise rotations. No drop is observed after clockwise rotation or in the fixed condition. *Connie Wang, Caltech*

Our participants' brains only responded when the vertical component of the field was pointing downwards at about 60 degrees (while horizontally rotating), as it does naturally here in Pasadena, California. They did not respond to unnatural directions of the magnetic field – such as when it pointed upwards. We suggest the response is tuned to natural stimuli, reflecting a biological mechanism that has been shaped by natural selection.

Other researchers have shown that animals' brains filter magnetic signals, only responding to those that are environmentally relevant. It makes sense to reject any magnetic signal that is too far away from the natural values because it most likely is from a magnetic anomaly - a lighting strike, or lodestone deposit in the ground, for example. One early report on birds showed that robins stop using the geomagnetic field if the strength is more than about 25 percent different from what they were used to. It's possible this tendency might be why previous researchers had trouble identifying this magnetic sense – if they cranked up the strength of the magnetic field to "help" subjects detect it, they might have instead ensured that subjects' brains ignored it.

Moreover, our series of experiments show that the receptor mechanism – the biological magnetometer in human beings – is not electrical induction, and can tell north from south. This latter feature rules out completely the so-called "quantum compass" or "cryptochrome" mechanism which is popular these days in the animal literature on magnetoreception. Our results are consistent only with functional magnetoreceptor cells based on the biological magnetite hypothesis. Note that a magnetite-based system can also explain all of the behavioral effects in birds that promoted the rise of the quantum compass hypothesis.

Brains register magnetic shifts, subconsciously

Our participants were all unaware of the magnetic field shifts and their brain responses. They felt that nothing had happened during the whole experiment – they'd just sat alone in dark silence for an hour. Underneath, though, their brains revealed a wide range of differences. Some brains showed almost no reaction, while other brains had alpha waves that shrank to half their normal size after a magnetic field shift.

It remains to be seen what these hidden reactions might mean for human behavioral capabilities. Do the weak and strong brain responses reflect some kind of individual differences in navigational ability? Can those with weaker brain responses benefit from some kind of training? Can those with strong brain responses be trained to actually feel the magnetic field?

A human response to Earth-strength magnetic fields might seem surprising. But given the evidence for magnetic sensation in our animal ancestors, it might be more surprising if humans had completely lost every last piece of the system. Thus far, we've found evidence that people have working magnetic sensors sending signals to the brain – a previously unknown sensory ability in the subconscious human mind. The full extent of our magnetic inheritance remains to be discovered.

NEWSNEUROSCIENCE

People can sense Earth's magnetic field, brain waves suggest

A new study hints that humans have magnetoreception abilities, similar to some other animals

ANIMAL MAGNETISM Like birds, bacteria and other creatures with an ability known as magnetoreception, humans can sense Earth's magnetic field (illustrated), a new study suggests.

MARCH 18, 2019

A new analysis of people's brain waves when surrounded by different magnetic fields suggests that people have a "sixth sense" for magnetism.

Birds, fish and some other creatures can sense Earth's magnetic field and use it for navigation (*SN: 6/14/14, p. 10*). Scientists have long wondered whether humans, too, boast this kind of magnetoreception. Now, by exposing people to an Earth-strength magnetic field pointed in different directions in the lab, researchers from the United States and Japan have discovered distinct brain wave patterns that occur in response to rotating the field in a certain way.

These findings, reported in a study published online March 18 in *eNeuro*, offer evidence that people do subconsciously respond to Earth's magnetic field — although it's not yet clear exactly why or how our brains use this information.

"The first impression when I read the [study] was like, 'Wow, I cannot believe it!'" says Can Xie, a biophysicist at Peking University in Beijing. Previous tests of human magnetoreception have yielded inconclusive results. This new evidence "is one step forward for the magnetoreception field and probably a big step for the human magnetic sense," he says. "I do hope we can see replications and further investigations in the near future."

During the experiment, 26 participants each sat with their eyes closed in a dark, quiet chamber lined with electrical coils. These coils manipulated the magnetic field inside the chamber such that it remained the same strength as Earth's natural field but could be pointed in any direction. Participants wore an EEG cap that recorded the electrical activity of their brains while the surrounding magnetic field rotated in various directions.

This setup simulated the effect of someone turning in different directions in Earth's natural, unchanging field without requiring a participant to actually move. (Complete stillness prevented motor-control thoughts from tainting brain waves due to the magnetic field.) The researchers compared these EEG readouts with those from control trials where the magnetic field inside the chamber didn't move.

Joseph Kirschvink, a neurobiologist and geophysicist at Caltech, and colleagues studied alpha waves to determine whether the brain reacts to changes in magnetic field direction. Alpha waves generally dominate EEG readings while a person is sitting idle but fade when someone receives sensory input, like a sound or touch.

Sure enough, changes in the magnetic field triggered changes in people's alpha waves. Specifically, when the magnetic field pointed toward the floor in front of a participant facing north — the direction that Earth's magnetic field points in the Northern Hemisphere — swiveling the field counterclockwise from northeast to northwest triggered an average 25 percent dip in the amplitude of alpha waves. That change was about three times as strong as natural alpha wave fluctuations seen in control trials.
ROTATION REACTION When downward-pointing magnetic fields were rotated counterclockwise, from northeast to northwest, researchers saw a significant dip in participants' alpha brain waves (left). Alpha waves are similarly dampened when someone receives sensory input like a sound or smell. This response was not seen when downward fields rotated clockwise (center) or were held steady (right).
Curiously, people's brains showed no responses to a rotating magnetic field pointed toward the ceiling — the direction of Earth's field in the Southern Hemisphere. Four participants were retested weeks or months later and showed the same responses.

"It's kind of intriguing to think that we have a sense of which we're not consciously aware," says Peter Hore, a chemist at the University of Oxford who has studied birds' internal compasses. But "extraordinary claims need extraordinary proof, and in this case, that includes being able to reproduce it in a different lab."

Questions raised

If these findings are replicable, they pose several questions — such as why people seem to respond to downward- but not upward-pointing fields. Kirschvink and colleagues think they have an answer: "The brain is taking [magnetic] data, pulling it out and only using it if it makes sense," Kirschvink says.

Participants in this study, who all hailed from the Northern Hemisphere, should perceive downward-pointing magnetic fields as natural, whereas upward fields would constitute an anomaly, the researchers argue. Magnetoreceptive animals are known to shut off their internal compasses when encountering weird fields, such as those caused by lightning, which might lead the animals astray. Northern-born humans may similarly take their magnetic sense "offline" when faced with strange, upward-pointing fields.
This explanation "seems plausible," Hore says, but would need to be tested in an experiment with participants from the Southern Hemisphere.

The brain's attention to counterclockwise but not clockwise rotations "is something surprising that we don't really have a good explanation for," says coauthor Connie Wang, who studies magnetoperception at Caltech. Some people may respond to clockwise rotations, just like some people are left-handed rather than right-handed, or clockwise rotations generate brain activity not captured in the alpha wave signal, she says.

Even accounting for which magnetic changes the brain picks up, researchers still don't know what our minds might use that information for, Kirschvink says. Another lingering mystery is how, exactly, our brains detect Earth's magnetic field. According to the researchers, the brain wave patterns uncovered in this study may be explained by sensory cells containing a magnetic mineral called magnetite, which has been found in magnetoreceptive trout as well as in the human brain (*SN: 8/11/12, p. 13*). Future experiments could confirm or eliminate that possibility.

With this first compelling evidence that humans are subconsciously processing magnetic signals, "we can [try to] identify the brain region it originates from and try to identify the nature of the cells" responsible, says Michael Winklhofer, a magnetoreception researcher at the University of Oldenburg in Germany. "This is really the first step."

Memory Is Not Confined to Our Brains, Scientists Discover

Microscope image of neurons from a mouse's cortex colored in red yellow and green

Our brain isn't the only place memories form in our body. New York University (NYU) researchers have discovered learning through repetition may be fundamental to all of our cells. The process may also help explain why taking breaks is such a powerful learning tool.

"Learning and memory are generally associated with brains and brain cells alone, but our study shows that other cells in the body can learn and form memories, too," says neuroscientist Nikolay Kukushkin.

Better understanding of how this process works could lead to more effective treatments for learning and memory problems, Kukushkin explains.

Many learn the hard way that cramming for exams doesn't create the most reliable or long term memories. Multiple cycles of chemical activity through a repeated behavior is what triggers the memory-formation process among our neurons, encoding incresasingly stronger memories. This phenomenon is called the massed-spaced effect and is highly conserved in all animals at both the cellular and behavioral levels.

By exposing non-brain nerve and kidney cells to similar chemical patterns in the lab, Kukushkin and colleagues showed for the first time that these tissues experience massed-spaced effect too. Genes associated with memory formation in neurons also seemed to be activated within these cells, based on measures of a byproduct of the genes' expression called luciferase.

"The ability to learn from spaced repetition isn't unique to brain cells, but, in fact, might be a fundamental property of all cells," explains Kukushkin.

How the nerve and kidney cells responsed depended on the number of rounds of protein kinases A and C (PKA and PKC) they were treated with. These chemical 'training pulses' are known components of memory forming signaling cascades.

"A three-minute pulse did turn on the 'memory gene,' but only for an hour or two, whereas after four pulses, the gene was turned on stronger, and stayed on for days," Kukushkin writes for Psychology Today.

The cell responses also depended on the time between pulses. These factors varied how strongly the memory-forming molecules were activated, and for how long – exactly what happens with our neurons.

"Memory exists not only in the brain, but throughout our body, and this 'body memory' could play a role in health and disease," writes Kukushkin.

There's still much to learn about how this all works inside human bodies. Previously the researchers found increasing interactions between PKA and enzymes called extracellular signal-regulated kinases in sea hares (Aplysia) – animals commonly used to study neuron behavior – not only enhanced learning but could repair learning deficits too.

"We will need to treat our body more like the brain," Kukushkin recommends. "For example, consider what our pancreas remembers about the pattern of our past meals to maintain healthy levels of blood glucose or consider what a cancer cell remembers about the pattern of chemotherapy."

This research was published in *Nature Communications*.

Meta's Ray-Bans Can Now Do Real-Time Live AI And Translation

Meta's Ray-Bans are becoming live AI glasses now. Scott Stein/CNET© Provided by CNET

Meta's camera-equipped Ray-Bans have had a lot of AI features onboard already, but they're getting two more big ones. Always-on continuous AI assistance is arriving onto the glasses starting today for owners who have early access to Meta's features, as well as onboard translation. Both these features were demoed by Mark Zuckerberg at Meta's Connect developer conference earlier this year.

The features involve continuous audio and camera recording as opposed to specific individual prompts, allowing the Ray-Bans to be used for an extended period of time with the AI features turned on. Saying "Meta, start Live AI" begins the always-on feature. The glasses' LED light stays on when always-on live AI is activated, and Meta keeps a recording of the conversation that can be referred to throughout the AI session. For translation, it should work automatically while talking, with the translation coming in via the glasses with a slight delay.

The live AI assistance is similar to what Google just demonstrated on its own prototype glasses this month via Gemini and Android XR, arriving next year.

The always-on AI takes a hit on battery life: expect 30 minutes of use before needing a recharge, according to Meta. But this type of always-on camera-assisted AI is exactly what more tech companies are going to be exploring in the next year. I'll follow up with impressions when I get a chance to test it for myself.