RS REPORTS

NEURALINK, ELON MUSK, AND THE RACE TO PUT CHIPS INTO OUR BRAINS

Though brain chips are all over TV and the news now with Neuralink, scientists like those at Caltech have been working on the technology for decades. And some question Musk's approach

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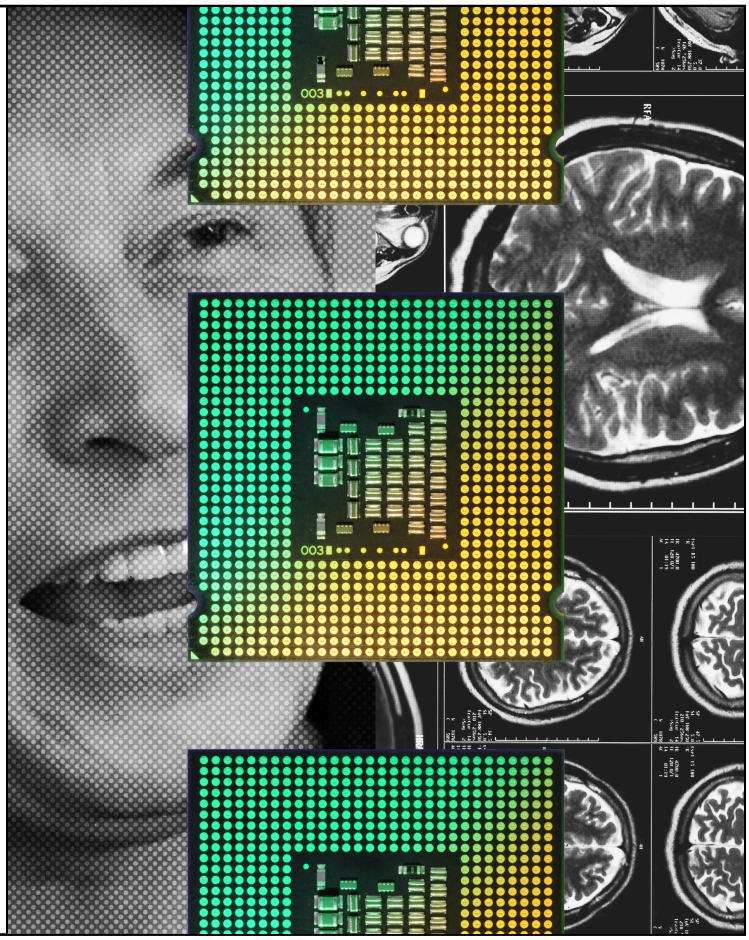

There's a 3D hand on a black screen. J. Galen Buckwalter concentrates on the image, trying to move one of the virtual hand's fingers — with his mind.

For more than 50 years, Buckwalter hasn't felt his fingers after breaking his neck in an accident as a teenager. But today, thanks to a research lab at California Institute of Technology (Caltech) that implanted him with a brain computer interface (BCI), Buckwalter is a pioneer exploring the frontiers of brain science.

Buckwalter only needed a couple of sessions to master the control of a computer cursor — some participants needed much longer. Now he attempts to move two fingers and a thumb. A large blue dot slides back and forth over the virtual index finger as he tries to coax it to life. Eventually he can move all three digits — and can actually *feel* the virtual fingers he's trying to move.

"That was the 'holy shit' moment, that this really feels like my hand," Buckwalter says with a grin in a video call. It may seem like a small step, but this was a giant leap for Buckwalter, 69, the self-proclaimed "neuronaut."

The Caltech lab where Buckwalter is a participant is run by Richard Andersen, 74, one of the world's foremost neuroscientists who has been working on implants for decades. His lab is currently studying five humans with long-term brain implants. These participants have moved objects with robotic arms, operated semi-autonomous cars as part of an **experiment in collaboration with Ford**, and even felt natural touch again.

Brain implants are very much part of the popular imagination right now — the hit show *Severance* fictionalizes a worst-case scenario for the technology — and **Elon Musk**'s BCI company **Neuralink** has swallowed most of the news attention, like the videos of Neuralink's participants **playing video games and moving robotic arms**.

Caltech postdoc David Bjånes works with a patient who has brain implants.

But Neuralink's headline-grabbing work builds on the painstaking achievements of research labs like Caltech's. "The BCI companies of today are standing on the shoulders of academic giants who have been developing BCIs for decades," says Rajesh Rao, co-director of the Center for Neurotechnology at the University of Washington.

Musk's goal for his company also diverges from his academic forbearers. The world's richest man is explicitly focused on "enhancement" — his sci-fi dream is to turn BCIs into mass products for able-bodied people, merging our brains with computers. While academic labs like Caltech are focused on better understanding the brain so they can help people with conditions like Buckwalter's, Musk wants to give people superhuman vision and total recall: "If it's extremely safe, and you can have superhuman abilities, and let's say you can upload your memories, so you wouldn't lose memories, then I think probably a lot of people would choose to have it," he **told podcaster Lex Fridman last year**. "It would supersede the cellphone, for example."

Dr. Richard Andersen, one of the world's foremost neuroscientists, runs Caltech's lab and has been working on implants for decades.

LANCE HAYASHIDA/CALTECH

Neuralink's staff **has basically said** that they don't need to understand how the brain works to roll out this cyborg future. To those in the know, this seems short-sighted. "New knowledge of how the brain works leads to more advanced neural prosthetics," as Andersen says. Musk's pushy approach also risks setting back this work at a crucial moment, according to others in the field.

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"The top leaders at Neuralink in place right now are definitely trying to do the right thing," one expert, who is in touch with Neuralink staff and asked to remain anonymous, tells *Rolling Stone*. But they point to "crazy pressure from the top," while raising some of the same concerns highlighted in a 2020 **STAT News investigation** that reported a "chaotic internal culture" and a **Reuters** 2023 report on "tensions inside Neuralink over development pace." Neuralink and Musk did not respond to a detailed list of questions from *Rolling Stone*. Current individual employees also did not respond to requests for comment for this piece.

With Musk's recent cost-cutting role in government — **already linked** to the firing of those in the Food and Drug Administration (FDA), including some staff overseeing Neuralink's clinical trial applications — there's more attention on the company than ever, with some wondering if the guardrails have come off.

IN JULY 2019, MUSK **strode onstage** in San Francisco wearing a suit with a white shirt, no tie, to make his first presentation about Neuralink. While the first human volunteers would be paralyzed patients, the ultimate goal was to avoid mankind being **"left behind"** by advancing tech, namely AI.

"This is going to sound pretty weird," he said, shoulders hunched, but the objective was to achieve "symbiosis with artificial intelligence." He added: "This is extremely important." The following year, in an interview with **Joe Rogan**, Musk made an even bigger claim: Implantees would be able to "save state" like in a video game, enabling someone to "restore that state into a biological being if you wanted to in the future."

Elon Musk, who founded Neuralink in 2016, envisions his venture as one day being capable of merging brains with computers.

MARCIO JOSE SANCHEZ/AP

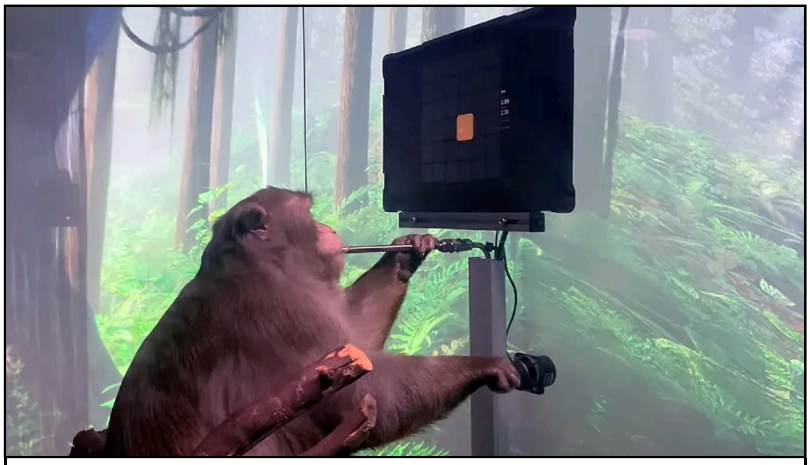
Despite Musk's interventions bringing the field an unprecedented level of prominence in the media, brain implants have been around for decades. In the 1960s, neurophysiologist José Delgado implanted bulls with wireless devices to stop them in their tracks as they charged **toward him**. In 1973, University of California in Los Angeles' Jacques Vidal, who coined the term "brain-computer interface," used noninvasive electroencephalograms (EEGs) — small sensors applied to the scalp — to allow participants to control a cursor-like object on a computer screen. There followed considerable public blowback over fears of mind control, particularly as the **Soviet Union conducted its own research**. Only in the 1990s did the pace pick up again, including the development of the microelectrode platform called the Utah Array. In 2004, **Matt Nagle** became the first paralyzed person to be implanted with the Utah Array, enabling him to move a cursor, check email, operate a TV, and open and close a prosthetic hand. The Utah Array would become the gold standard for BCIs, used in many academic research labs.

Musk wanted to popularize a different kind of brain implant — one that was wireless.

In 2016, Musk founded Neuralink with eight engineers and neuroscientists, including Philip Sabes, a professor emeritus at University of California, San Francisco (UCSF); Sabes had been working at UCSF on thin-film electrodes that could be robotically

implanted at the micron-scale using a "sewing machine." Although Neuralink **was registered** as a "medical research" company, a key goal was human-AI integration, as **later specified** by Musk in a conversation with **Wait But Why blogger** and author Tim Urban.

At times in the years since Neuralink's founding, Musk was **reportedly** frustrated by the company's progress. Before Neuralink could work with humans, it had to conduct extensive trials with animals. To begin with, this mostly involved rats. In his 2019 presentation, Musk revealed Neuralink had started testing primates, too. "A monkey has been able to control the computer with his brain. Just FYI," he claimed.



In a Neuralink experiment, a monkey plays the rudimentary video game Pong with its mind.

Accusations of animal cruelty led to a **federal probe in 2022** for violations of the Animal Welfare Act. According to Reuters, which cited documents and interviews with 20 current and former employees, excessive **pressure** and rushed timelines resulted in botched experiments causing the deaths of at least 1,500 animals — including monkeys, sheep, and pigs — over a four-year period. Neuralink denied the animal cruelty claims at the time. (In July 2023, the federal probe found **no breaches** of animal welfare rules apart from a 2019 incident the company had already reported.)

In 2023, Neuralink got permission from the FDA to begin testing with humans. That year, Neuralink raised around $325 million from investors who valued the company in excess of $3 billion.

In 2024, Neuralink announced its first human participant: Noland Arbaugh, a thirtysomething quadriplegic, was implanted with a wireless chip smaller and supposedly more powerful than the Utah Array. Although far less invasive than procedures at labs like Caltech's, Neuralink's implant still **involved** a small part of the skull being permanently removed; the implant sits in this space with a flap of skin on top. A neurosurgeon oversaw the robot's surgery, but the company's ultimate goal is to fully **automate the procedure**.

Noland Arbaugh, who is paralyzed from an accident, was the first patient to take part in the clinical trial of humans testing Musk's Neuralink device.

REBECCA NOBLE/THE NEW YORK TIMES/REDUX

With practice, Arbaugh was able to use the BCI to control a computer cursor and play video games. But there were problems. Only a month after his surgery, **around 85 percent** of the threads implanted in his brain had come loose. In August 2024, it announced a second participant, implanted with a more advanced chip that enabled him to design 3D objects using computer-aided design software. In late January, Neuralink posted a clip of a robotic arm writing on a whiteboard, supposedly under the control of a third participant, and on April 27, Musk **shared a video** of this participant, who has ALS and is unable to speak, describing how his implant had enabled him to communicate again via a computer. More recently, the number of patients has accelerated, with Neuralink claiming it now has **nine human participants**.

Like studies at academic labs, all of Neuralink's **participants are paralyzed**. While Musk has more recently hailed the potential for Neuralink to restore a person's ability to walk or even cure **their dementia**, he has more often alluded to a different objective. During an **hourlong presentation in July 2024**, Musk claimed that anyone with his implants would soon be able to communicate faster than a person with a fully functional body.

"We want to give people superpowers," he said.

SO FAR, NEURALINK HAS LARGELY built on achievements already demonstrated in the field — cursor control, click control, and robotic arm control. "How I would see it is they're basically checking off these milestones," the expert in touch with Neuralink staff tells *Rolling Stone*. "Everything Musk does attracts an outsized level of attention.... I think most scientists prefer other people to measure the significance of their work, whereas Musk is doing the opposite, and labeling everything he's done as brand new and significant."

A prototype illustration shows the NeuraLink integrated system.

GDA/AP

There are unique elements to Neuralink's BCI, such as the robotic surgery used to implant it, as well as the wireless technology. But other companies use even less-invasive methods. Precision Neuroscience, founded by a former Neuralink co-founder, has developed a flexible electrode array thinner than a human hair,

which the company describes as "minimally invasive." Synchron is testing a device that's inserted into the brain through a blood vessel; the company also uses a **generative chat feature powered by OpenAI** to assist relevant participants with communication (it was recently **reported** that OpenAI co-founder Sam Altman is raising funds for a BCI startup that would compete with Neuralink). And the method of implanting electrode threads into the cortex was first developed by Philip Sabes while he worked at UCSF, before he left and co-founded Neuralink.

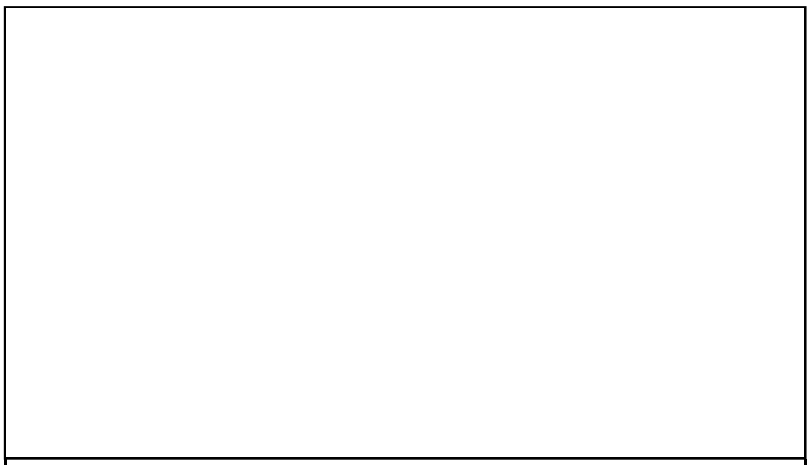
There are also downsides to going wireless. Caltech postdoc David Bjånes notes that, while Neuralink's device records neurons from more channels than, for example, the 384 channels provided by six Utah Arrays as in Buckwalter's case, it currently only records from one brain area — by contrast, Caltech's devices record from five brain areas concurrently. With different participants having implants in different parts of the brain, the researchers have a more holistic view of how the brain performs various functions.

Neuralink's device also transmits a compressed version of its brain signal due to bandwidth limitations from being wireless, whereas Caltech can record uncompressed, high bandwidth broadband signals on all their channels. "As a scientist, I am not willing to sacrifice signal if I don't have to," Bjånes says. "A wired solution that gives me as much signal as possible — I'm going to choose that every time over another technology." For patients, there's a huge advantage to a wireless BCI, but that comes at the expense of gaining new knowledge about the brain that can help future patients. "I think the wireless technology will get there," Bjånes says. "It just is not quite mature enough."

Previously, Neuralink has been pilloried for its lack of transparency. After Musk announced on X in January 2024 that the first human had been implanted with Neuralink's device, **experts in the field and former regulatory staff** expressed concerns at the piecemeal doling out of information, with specific criticism for not registering its trial at the National Institute of Health's website **ClinicalTrials.gov** — a common practice even for so-called "early feasibility" devices like Neuralink's. Medical ethicists described Neuralink's and Musk's approach as **"science by press release."** In May, Neuralink did register on ClinicalTrials.gov and has since shared more details of its studies. But it's still unclear, for example,

how its robotic surgery exactly works, at least to anyone outside Neuralink.

And as Musk continues to make bold claims in an increasingly competitive field, experts note that, given past concerns raised by Neuralink employees, something could go wrong and set the field back years both in terms of willing participants and private investors due to the long shadow Musk casts. "The 'move fast, break things, and fix it later' philosophy of Big Tech is going to be disastrous if applied to BCIs," says Rajesh Rao, the University of Washington professor, who argues that commercial companies like Neuralink should embed ethicists in their teams.



David Bjånes works in the lab.

PETER HOLDERNESS/CALTECH

A former Neuralink engineer tells *Rolling Stone* it is "hard for anything to advance super fast for a class 3 medical device," noting that every advance takes "immense effort," testing and preclinical/clinical trials. And they claim the company moves fast "without compromising safety."

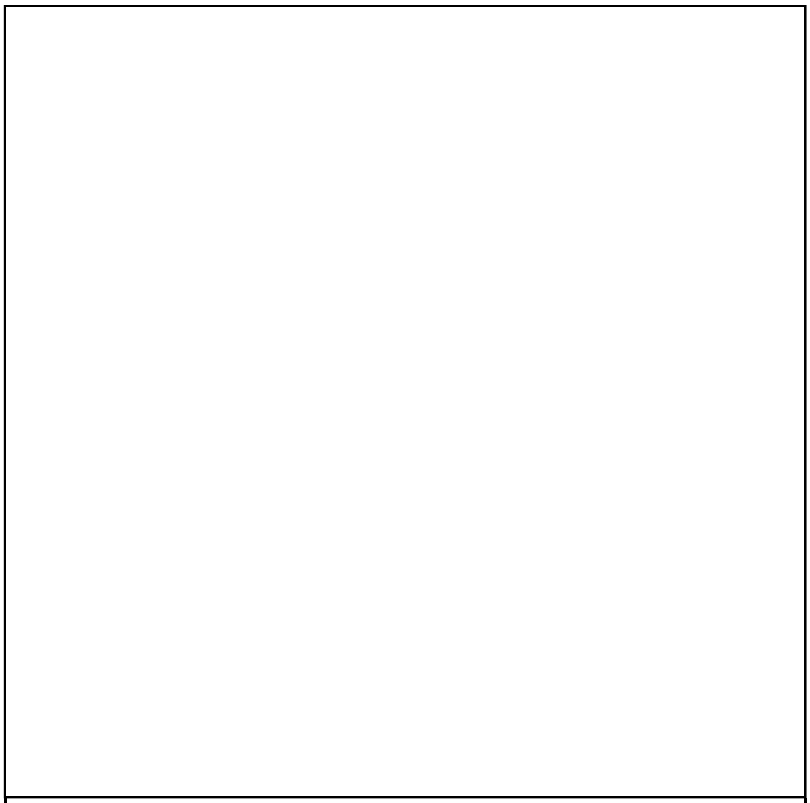
Even so, concerns about Neuralink's impact on the field only grew in the wake of Musk's so-called Department of Government Efficiency (DOGE) instigating mass layoffs of federal staff, some directly impacting Neuralink. This sparked concern that guardrails around approval for Neuralink trials had been removed. Phyllis Fong, the USDA's longtime inspector general who launched the ongoing probe into Neuralink for alleged animal cruelty, was **forced out of her job in January**. In mid-February, 20 staff members in the FDA office of neurological and physical medicine devices, including several who oversaw Neuralink, were also fired. (Shortly after

layoffs in the FDA, hundreds were reportedly asked to rejoin, though it is unclear if any staff specifically reviewing Neuralink were rehired.) The cuts included reviewers overseeing clinical-trial applications by Neuralink and other companies creating BCI devices. (In April, Neuralink also falsely self-certified as a "small disadvantaged business" **on a federal filing**, qualifying Musk's company for funding aimed at promoting racial and ethnic diversity. As of this summer, there wasn't evidence that they'd received the funding.) In response to criticism that Musk was removing officials responsible for regulating his companies, the White House **insisted** at the time that he had pledged to avoid conflicts of interest.

BUCKWALTER WAS ONLY 17 when he leapt from high rocks into the Susquehanna River in Pennsylvania, breaking his neck and doing irreparable damage to his spinal cord. He spent a year in a state hospital for what were then called "crippled" children. While some of the other injured kids were in and out within a month, Buckwalter's convalescence was slow. "I kind of had to stumble my way along," he says. "It was the dark ages of rehabilitation medicine."

But Buckwalter did find his way, and he has gone on to live a full life by any measure. He ended up being a researcher for 15 years, writing a paper on estrogen replacement therapy for women diagnosed with Alzheimer's disease that is still cited often, as is his groundbreaking research into so-called "mommy brain" cognition during pregnancy, which landed him on morning news shows in the 1990s. Buckwalter conducted initial research and wrote the matching algorithm for the dating website eHarmony, founded in 2000. For a quarter century, Buckwalter has also been the frontman of a David Bowie-inspired rock band called **Siggy**, which still performs live.

Many quadriplegics don't make it to Buckwalter's age. "Fifty years post-spinal cord injury is a pretty small population of folks," he says.



J. Galen Buckwalter, a self-proclaimed "neuronaut," has had life-changing experiences as a participant in the Caltech lab.

COURTESY OF J. GALEN BUCKWALTER

In 2023, a friend and colleague who had a neuroscience Ph.D. from Caltech told him about a lab at the private university in Pasadena researching brain implants. The surgery itself involved cutting into Buckwalter's skull to install six Utah arrays. The implants are designed to both "read" and "write": The electrodes record neurons firing as well as stimulating activity. Buckwalter's pioneering case also involves the world's first chronic implant inside the dorsolateral prefrontal cortex, where high-level reasoning and possible participation in language takes place.

Even in the inherently more cautious academic sphere of BCIs, there are challenges for participants like Buckwalter. After falling earlier this year, he fractured his femur and damaged one of the pedestals protruding from his head, and it has taken Caltech's neurosurgeons some time to bring the affected arrays online. He has also belatedly realized he doesn't technically have ownership of his data — the information gathered from his brain by the arrays during lab work with Caltech — which complicates a proposed collaboration over the creation of a virtual clone of Buckwalter with a former student of his, Thomas Parsons, working in AI at Arizona State University.

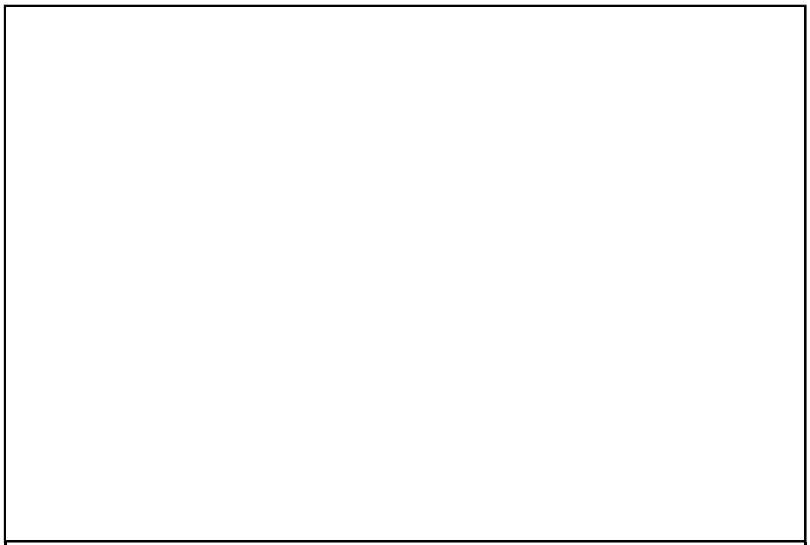
Parsons has been scraping anything Buckwalter has ever written or said on record to integrate into a large language model. This plan is to have Buckwalter's BCI interact directly with his virtual clone,

offering unprecedented insights into the holy grail of neuroscience — the mechanics of consciousness itself. But if Buckwalter can't access his Caltech data, the ambitious project may be imperilled.

Buckwalter and other brain implantees are now trying to collectively organize behind a so-called BCI Pioneers manifesto, and are working with an attorney on a consent form addendum for all brain implant procedures. Buckwalter has proposed the catchy slogan: "My brain, my data."

THERE ARE MAJOR DIFFERENCES between academic researchers and commercial companies — and yet the fates of both are bound together. "The failure and success of any one of us is all of ours," Bjånes says.

One way of warding off this danger could be by greater collaboration between companies and academic research labs. One company, Onward Medical, collaborates with Rao's center at the University of Washington, and another called Blackrock Neurotech, which produces the Utah Array, collaborates with multiple research labs. Neuralink has made no such collaboration public.



With a brain chip, lab participants can move a virtual hand.

LANCE HAYASHIDA/CALTECH

Experts speaking to *Rolling Stone* say Neuralink clearly has an important role to play in the field's future, both in raising public awareness and the transformative potential of the company achieving its goal of implanting thousands of humans.

"Neuralink's strength is in its ability to commercialize such an intricate piece of tech," says the ex-Neuralink engineer. "Sure, this has existed in labs, but no one can feasibly bring it to market at scale." Currently only a handful of participants are signed up to each academic research lab. If Neuralink's work means there are many more participants with BCIs, and Musk releases the API to enable other researchers to access the data, it could be a game changer. Given Neuralink's relative opacity, that seems unlikely.

At the same time, Musk continues to make fantastical-sounding claims. Last year he predicted that within two decades, hundreds of millions of people would be using Neuralink's implants. He envisions a future in which his company inaugurates superhuman cyborgs — a techno-dystopian "symbiosis" with machines and artificial intelligence.

AI has an important role to play with BCIs, particularly via the use of large language models (LLM) to assist the decoding of speech, learning an individual's repeated patterns of speech and generating a voice that sounds like their own. AI has also helped patients communicate as with rival company Synchron's OpenAI-powered generative chat feature. Musk's leading contribution to the AI field so far has been Grok. But his X-native chatbot has repeatedly caused controversy, **whether ranting** about "white genocide" in South Africa or **praising Hitler**, and replying to users with antisemitic comments. There may be reason to fear what Musk could do with experimental brain tech after seeing how Grok has turned out.

Meanwhile, Musk's big claims about brain implants' potential could end up triggering a public backlash as was seen in the 1970s. They even highlight a rift in President Trump's coalition between the tech right and those wary of Big Tech. **Former top Trump strategist Steve Bannon**, a staunch critic of Musk's transhumanist philosophy, warned in January that within 10 years, brain chips would threaten humanity as we know it, as people could face a dilemma over whether to enhance themselves or fall behind peers.

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UCSF's Edward Chang sees his lab's place in the field as distinct from many commercial companies. "My goal, ultimately, is quite different," he says. Instead of Musk's sci-fi enhancement dream, Chang's research seeks new knowledge that can relieve the suffering of his patients, and even more importantly, "trying to understand who we are as humans," he says. "I think ultimately, that's a much more ambitious goal than enhancement."

Using BCIs to advance our understanding of the brain comes at a moment when artificial intelligence also poses existential questions for humanity. As Chang says, "I personally think that it's more important than ever, actually, to understand what makes us human."

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