BUILDING THE BIONIC BRAIN

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INTRODUCTION

The mind is the final frontier for computing. New technologies will allow us to connect our brains to computers to share our thoughts and control devices, and expand the capabilities of our minds to rival even super-smart AI. Take a look at the current state of the art, where we go next, and the challenges that lie ahead.

WHAT IS A BRAIN-COMPUTER INTERFACE? EVERYTHING YOU NEED TO KNOW ABOUT BCIS, NEURAL INTERFACES AND THE FUTURE OF MIND-READING COMPUTERS

Systems that allow humans to control or communicate with technology using only the electrical signals in the brains or muscles are fast becoming mainstream. Here's what you need to know.

BY: JO BEST


IMAGE: ISTOCKPHOTO

What is a brain-computer interface? It can't be what it sounds like, surely?

Yep, brain-computer interfaces (BCIs) are precisely what they sound like—systems that connect up the human brain to external technology.

It all sounds a bit sci-fi. Brain-computer interfaces aren't really something that people are using now, are they?

People are indeed using BCIs today—all around you. At their most simple, a brain-computer interface can be used as a neuroprosthesis—that is, a piece of hardware that can replace or augment nerves that aren't working properly. The most commonly used neuroprostheses are cochlear implants, which help people with parts of their ear's internal anatomy to hear. Neuroprostheses to help replace damaged optic nerve function are less common, but a number of companies are developing them, and we're likely to see widespread uptake of such devices in the coming years.

So why are brain-computer interfaces described as mind-reading technology?

That's where this technology is heading. There are systems, currently being piloted, that can translate your brain activity—the electrical impulses—into signals that software can understand. That means your brain activity can be measured; real-life mind-reading. Or you can use your brain activity to control a remote device.

When we think, thoughts are transmitted within our brain and down into our body as a series of electrical impulses. Picking up such signals is nothing new: doctors already monitor the electrical activity in the brain using EEG (electroencephalography) and in the muscles using EMG (electromyography) as a way of detecting nerve problems. In medicine, EEG and EMG are used to find diseases and other nerve problems by looking for too much, too little or unexpected electrical activity in a patient's nerves.

Now, however, researchers and companies are looking at whether those electrical impulses could be decoded to give an insight into a person's thoughts.

- Mind-reading systems: Seven ways brain computer interfaces are already changing the world
- 10 years from now your brain will be connected to your computer

Can BCIs read minds? Would they be able to tell what I'm thinking right now?

At present, no. BCIs can't read your thoughts precisely enough to know what your thoughts are at any given moment. Currently, they're more about picking up emotional states or which movements you intend to make. A BCI could pick up when someone is thinking 'yes' or 'no', but detecting more specific thoughts, like knowing you fancy a cheese sandwich right now or that your boss has been really annoying you, are beyond the scope of most brain-computer interfaces.

OK, so give me an example of how BCIs are used.

A lot of interest in BCIs is from medicine. BCIs could potentially offer a way for people with nerve damage to recover lost function. For example, in some spinal injuries, the electrical connection between the brain and the muscles in the limbs has been broken, leaving people unable to move their arms or legs. BCIs could potentially help in such injuries by either passing the electrical signals onto the muscles, bypassing the broken connection and allowing people to move again, or help patients use their thoughts to control robotics or prosthetic limbs that could make movements for them.

They could also help people with conditions such as locked-in syndrome, who can't speak or move but don't have any cognitive problems, to make their wants and needs known.

What about the military and BCIs?

Like many new technologies, BCIs have attracted interest from the military, and US military emerging technology agency DARPA is investing tens of millions of dollars in developing a brain-computer interface for use by soldiers.

More broadly, it's easy to see the appeal of BCIs for the military: soldiers in the field could patch in teams back at HQ for extra intelligence, for example, and communicate with each other without making a sound. Equally, there are darker uses that the army could put BCIs too—like interrogation and espionage.

What about Facebook and BCIs?

Facebook has been championing the use of BCIs and recently purchased a BCI company, CTRL-labs, for a reported $1bn. Facebook is looking at BCIs from two different perspectives. It's working with researchers to translate thoughts to speech, and its CTRL-labs acquisition could help interpret what movements someone wants to make from their brain signals alone. The common thread between the two is developing the next hardware interface.

Facebook is already preparing for the way we interface with our devices to change. In the same way we've moved from keyboard to mouse to touchscreen and most recently to voice as a way of controlling technology around us, Facebook is betting that the next big interface will be our thoughts. Rather than type your next status update, you could think it; rather than touch a screen to toggle between windows, you could simply move your hands in the air.

- Facebook's 'mind-reading' tech startup deal could completely change how we control computers
- Type with your mind: We've achieved a first in brain-computer research, says Facebook

I'm not sure I'm willing to have a chip put in my brain just to type a status update.

You may not need to: not all BCI systems require a direct interface to read your brain activity.

There are currently two approaches to BCIs: invasive and non-invasive. Invasive systems have hardware that's in contact with the brain; non-invasive systems typically pick up the brain's signals from the scalp, using head-worn sensors.

The two approaches have their own different benefits and disadvantages. With invasive BCI systems, because electrode arrays are touching the brain, they can gather much more fine-grained and accurate signals. However, as you can imagine, they involve brain surgery and the brain isn't always too happy about having electrode arrays attached to it—the brain reacts with a process called glial scarring, which in turn can make it harder for the array to pick up signals. Due to the risks involved, invasive systems are usually reserved for medical applications.

Non-invasive systems, however, are more consumer friendly, as there's no surgery required—such systems record electrical impulses coming from the skin either through sensor-equipped caps worn on the head or similar hardware worn on the wrist like bracelets. It's likely to be that in-your-face (or on-your-head) nature of the hardware that holds back adoption: early adopters may be happy to sport large and obvious caps, but most consumers won't be keen to wear an electrode-studded hat that reads their brain waves.

There are, however, efforts to build less intrusive non-invasive systems: DARPA, for example, is funding research into non-surgical BCIs and one day the necessary hardware could be small enough to be inhaled or injected.

- AI can now read the thoughts of paralysed patients as they imagine they are writing
- Neural implants: Why connecting your brain to a computer will create a huge headache for everyone

Why are BCIs becoming a thing now?

Researchers have been interested in the potential of BCIs for decades, but the technology has come on at a far faster pace than many have predicted, thanks largely to better artificial intelligence and machine-learning software. As such systems have become more sophisticated, they've been able to better interpret the signals coming from the brain, separate the signals from the noise, and correlate the brain's electrical impulses with actual thoughts.

Should I worry about people reading my thoughts without my permission? What about mind control?

On a practical level, most BCIs are only unidirectional—that is, they can read thoughts, but can't put any ideas into users' minds. That said, experimental work is already being undertaken around how people can communicate through BCIs: one recent project from the University of Washington allowed three people to collaborate on a Tetris-like game using BCIs.

The pace of technology development being what it is, bidirectional interfaces will be more common before too long. Especially if Elon Musk's BCI outfit Neuralink has anything to do with it.

- Mind-reading technology is everyone's next big security nightmare
- Mind-reading technology: The security and privacy threats ahead

What is Neuralink?

Elon Musk galvanised interest in BCIs when he launched Neuralink. As you'd expect from anything run by Musk, there's an eye-watering level of both ambition and secrecy. The company's website and Twitter feed revealed very little about what it was planning, although Musk occasionally shared hints, suggesting it was working on brain implants in the form of 'neural lace', a mesh of electrodes that would sit on the surface of the brain. The first serious information on Neuralink's technology came with a presentation earlier this year, showing off a new array that can be implanted into the brain's cortex by surgical robots.

Like a lot of BCIs, Neuralink's was framed initially as a way to help people with neurological disorders, but Musk is looking further out, claiming that Neuralink could be used to allow humans a direct interface with artificial intelligence, so that humans are not eventually outpaced by AI. It might be that the only way to stop ourselves becoming outclassed by machines is to link up with them—if we can't beat them, Musk's thinking goes, we may have to join them.

ELON MUSK'S NEURALINK EXPLAINED: GET READY TO MERGE YOUR MIND WITH A COMPUTER

Elon Musk's secretive startup has promised to connect humans and machines. Here's a look at how it might work - and the barriers it will need to overcome.

BY: JO BEST

Neuralink is two-year-old startup that's yet to release a single product, but which is promising to build the technology to connect up human brains with computers.

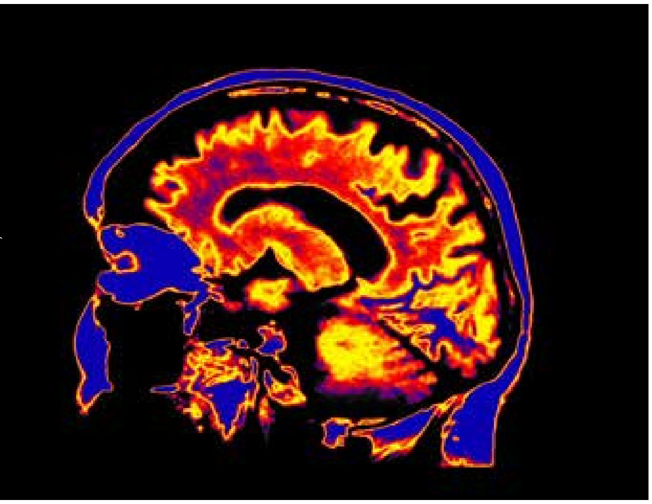
IMAGE: GETTY IMAGES/ISTOCKPHOTO

If it was run by anyone other than Elon Musk, no one would give it a second look. But, with the entrepreneur behind Tesla and Hyperloop at its helm, could Neuralink be really about to deliver a way to merge humans and machines?

Neuralink's stated goal is to develop ultra-high bandwidth brain computer interfaces to connect humans and machines. The job listings—which are pretty much the only thing you'll find on the company's sparse website—give you a flavour of the challenge that Neuralink, which recently reportedly raised $39m in new funding, will face.

For example, the company is looking for an engineer to work on the development of materials and processing methods that "do not currently exist" as part of its plan to develop high-density, reliable neural interfaces that are at the ground level of brain computer linking.

"These materials directly interact with tissue to pick up and send brain signals, consequently, this work is a key component in the final product," says the job ad with a certain amount of understatement. Another of Neuralink's vacancies is for an optical engineer to develop custom optics and imaging systems used directly in its surgical robot (after all, what else would install a brain computer interface apart from a surgical robot?).

In truth, the idea of brain computer interfaces (BCI) isn't new: in recent decades, computing has increased in power while the complexity and use of medical technologies like EEG and MRI have increasingly revealed the physical workings of the thinking brain. As a result, the possibility of directly connecting a human brain to computers in the outside world became less sci-fi dream and more realistic tech prospect.

The quest to build a functioning brain computer interface has spawned numerous separate strands of research over the years, all seeking to find ways to translate human thoughts into computer commands without the need for a physical action.

So far, much of the work on systems that connect brains with electronics have been undertaken with a medical goal in mind. Some of the first brain computer interfaces were neuroprostheses—systems designed to help those with neurological impairments regain lost function. The first neuroprostheses were designed to replace impaired senses, typically hearing and, more recently, elements of sight.

Other research efforts have focused on restoring lost physical capabilities: for example, creating a brain computer that would allow someone with a spinal injury to grasp an object by controlling a robot arm, or move a cursor using only their brain's electrical signals.

The early part of Neuralink's work may advance on this. The company has suggested the first applications will be aimed at certain types of brain injuries, such as stroke, cancer, and congenital problems (while they've given no indication what type of congenital lesions they're thinking of, cerebral palsy might be a likely candidate). In all three, there are often areas of functional brain separated by islands of brain where the neural cabling has died, often due to a lack of blood supply.

One of the odd things about human nerves is they aren't great at recovering after injury, so that once a connection has been sufficiently severed, it's unlikely to regrow (this is one of the reasons why transplanting limbs has traditionally been a challenge for medicine.) However, if an artificial implant could allow the signal from one functional area of the brain to reach another by leapfrogging the dead area, it could enable people with brain injuries to recover capabilities that have been lost.

If function can't be restored—for example, in the case of quadriplegia—BCIs can still be useful. BCIs could, for example, enable people to control robot avatars of themselves to carry tasks they aren't able to, or effectively use their thoughts to control a web interface.

And those are not the only medical conditions with which brain computer interfaces could help: epilepsy too, has been suggested as a potential target and seems a good one given the condition is a disorder of electrical signalling within the brain, as has Parkinson's, where deep brain stimulation is already helping to tackle some of the symptoms of the disease.

It has also been suggested Neuralink's work could be used to help combat Alzheimer's dementia or the gradual fading of memory that comes with old age. Such conditions present a far more complex challenge for BCI companies: many of the conditions mentioned in connection with Neuralink are those where the problem is chiefly one of signalling (think of it as a condition where messages can't get from point A to point B because there's a break in the road). Alzheimer's dementia and age-related memory loss are due to far larger structural problems in the brain: brain matter itself atrophies, meaning the message can't get from point a to point b because there's just no road, or points to start with, for that matter. (Interestingly, the shrinkage that happens in old age is typically due to under-stimulation—and what could be more stimulating than having huge chunk of computing infrastructure permanently plugged into your grey matter?)

Medicine may have spurred the genesis of brain computer interfaces, but the field has already expanded outside of healthcare: brains have been used to pilot drones, for example, and could one day end up being the way we control our smart homes.

But building a brain computer interface that allows you to do many things, rather than one that's used for a single application, could prove difficult, thanks to the limitations of both human and machine hardware. One of the greatest challenges that BCIs face is achieving a bidirectional information flow for multiple applications: human can talk to a machine, and the machine can talk back.

Ultimately, Neuralink is thinking much bigger, and going far beyond traditional medical technology. Longer term, the company wants to plumb in human intelligence to artificial intelligence, offering upgrades to everyday brains as a way of "democratising" smartness.

Musk has said before that he believes that AI is one of the greatest threats to humankind, and brain computer interfaces could be one way of tempering that threat—giving us a chance to keep up and even eventually become part of the super-intelligent AI, which is why a high bandwidth link is needed: to enable our minds to eventually communicate at the same pace as an AI.

Musk claimed late last year that Neuralink would unveil the first fruits of its work within months, and that work would "be better than anyone thinks is possible" (though it may be worth highlighting he did make that statement while smoking marijuana on the Joe Rogan radio show).

And when earlier this year he was asked for an update, Musk simply tweeted 'Coming soon'.

Despite Musk's promise of products on the horizon, there will likely be many, many years of work ahead before you'll be telepathically linked to your computer.

Before any new medical tech can hit the market, particularly anything reaching the brain, there will need to be an extensive period of pre-market testing in the lab using animals.

Reports suggest that Neuralink had been looking to build a new HQ with room for rodent testing. Rodents are typically used in neuroscience research due to structural similarities between rat and human brains—the Human Brain Project, a research effort to model the human brain in computing, has recently completed a model of the mouse brain. While the plans for the new HQ were apparently later ditched, the fact that the company was seeking a location suggests that the work has at least a degree of maturity to warrant testing. The company is reportedly funding primate research at the University of California, though the scope of the work is being kept under wraps.

One of the major issues that Neuralink will have to tackle is that existing brain computer interfaces are unidirectional and single application: in the case of artificial ears, information from the outside world is carried to the brain for the task of hearing; in the case of the thought-controlled robot, the information goes the other way to enable movement. Enabling bidirectional interfaces would prove challenging for both human and machine.

"It's very challenging to do from the machine side and even from the human side. If I want to change a channel on the TV, I have to imagine myself changing the channel, and if I want to close the door, I have to imagine another action within my brain to close the door. Just changing that imagination is very difficult to do quickly and it's very tiring as well—after 20 minutes you'll feel very fatigued because you're not used to doing that," Dr Marvin Andujar, assistant professor and director of the Neuro-Machine Interaction research lab at the University of South Florida, says.

To be able to control even a universal remote, say, would require humans to undertake a huge shift in thinking. "If we would like to control machines with our brains, it's very difficult for a human to do that right now because we're not trained like that to use our brain in that perspective—we'd need a lot of training to be able to use that type of technology," he added. It would be particular tricky for older people—children's neural plasticity, natural creativity and curiosity would mean they'd be likely to adapt to new interfaces far more easily.

While Musk hasn't been forthcoming about the nature of the product(s) that Neuralink is working on, he has discussed the need for a type of 'neural lace'—a nod to the Iain M Banks Culture novels where brain computer interfaces are common. Neural lace could work as "a digital layer above the cortex... just as your cortex works symbiotically with your limbic system, a third digital layer could work symbiotically with the rest of you," Musk has said.

Musk suggested that neural lace wouldn't necessarily mean brain surgery, and that it could be conveyed to the brain via the body's arteries or veins. There are already drugs that are programmed to travel through the bloodstream, but only activate once they've crossed the blood-brain barrier: it's not so far-fetched that suitable small electronics could also only switch on once they reach the brain.

For now, however, there are two main schools of thought on how to get the brain part and the computer part of the BCI to talk to each other. Under the invasive approach, the skull is opened up and electrodes are implanted onto the surface of the brain; under the non-invasive approach, the electrodes sit on the skull, and there's no surgery required.

Musk may hope for a blood-transmitted system, but it appears that Neuralink is looking towards a good old-fashioned invasive approach. Researchers associated with the company published a paper describing a system that would insert flexible polymer probes into the brain using a robotic insertion device described as a "sewing machine". The system has already been demonstrated on a rat, according to the paper, and used to record outputs from its brain.

However, the brain is a dense piece of matter, housing billions of neurons. For a multi-application brain computer interface to work, the interface would need to potentially access or interpret signals from all of them (certain neurones are thought to be exclusively dedicated to specific individuals including celebrities, for example). Accessing an individual neuron is a problem neuroscientists haven't cracked, let alone technology companies.

Pleasingly to our egos but problematically for programmers, each of our brains is unique in its electrical signals, meaning a BCI for one individual might not work for another. "For each person, we have our own unique brainwaves—it's like our own biometrics. It's going to make it very difficult to make a universal machine," Andujar says.

One interesting and thorny problem about building brain computer interfaces is that the human brain is as much a mystery as the depths of the oceans: while some parts of it have been well mapped, others are still opaque to science. That doesn't necessarily present as great a problem to brain computer interfaces as it might, however: in fact, brain computer interfaces are shedding light on the workings of the black box that is the human brain.

"We're learning more about how to control tools with the brain and we're learning more about how the brain works itself," Dr Jason Connolly, an assistant professor in the Department of Psychology at Durham University working on brain computer interfaces, said. As researchers begin to harness and interpret signals from the prefrontal cortex—one of the regions of the brain responsible for higher-level cognitions—and how that translates into actions, "that's also going to back-propagate and teach us about how the prefrontal lobe itself works".

But it's not just a question of better understanding our own wiring, we'll need to get higher powered electronics before BCIs can become commonplace. Ultimately, BCIs will need to be so simple they can be "controlled by a computer, iPad, or anything like that by an everyday person. That's the issue—basically developing a deep neural network to analyse the data. Now you can do it on a laptop—it's got to have a very good, very fast GPU, but you can do it. But if you want to make [a BCI] mobile, you want to make it down to the level of a phone or tablet to do the processing, at the moment we're not there yet. As computers move forward, I think that problem will be solved as well," Connolly said.

In the future, brain computer interfaces could ultimately allow the human brain to patch into artificial intelligences and other resources, giving the brain's computing power almost limitless upgrade potential. Would we use it to give ourselves da Vinci-style intelligence, or just upgrade to be the best Fortnite player the world has ever seen? Hopefully patching our brains into computers will not only bring us artificial intelligence, but artificial wisdom with it.

FACEBOOK'S 'MIND-READING' TECH STARTUP DEAL COULD COMPLETELY CHANGE HOW WE CONTROL COMPUTERS

Facebook's latest foray into brain computer interfaces is a reflection of the changing nature of hardware and how we interact with it.

BY: JO BEST

IMAGE: GETTY IMAGES/ISTOCKPHOTO

Earlier this week, Facebook announced it was acquiring CTRL-labs. The deal was variously reported as either the social media giant acquiring a "mind-reading tech company" or an outfit that makes "neural wristbands". In fact, the reality is much more complex—and could potentially signal the start of a complete overhaul of how we interact with technology.

The size of the acquisition hasn't been disclosed, but CNBC reported it was worth between $500m and $1bn, citing sources familiar with the deal. It may seem like a lot of money for a company whose developer kit is less than a year old, but Facebook isn't shy of taking expensive punts on what it believes are the frontrunners in emerging technologies—take its $2bn acquisition of VR gaming company Oculus Rift, for example.

So what's the CTRL-labs' appeal for Facebook?

CTRL-labs is one of the growing number of companies in a space known variously as brain computer interfaces (BCIs) or brain machine interfaces (BMIs).

"We spend a lot of time trying to get our technology to do what we want, rather than enjoying the people around us. We know there are more natural, intuitive ways to interact with devices and technology. And we want to build them. It's why we've agreed to acquire CTRL-labs. They will be joining our Facebook Reality Labs team where we hope to build this kind of technology, at scale, and get it into consumer products faster," Andrew Bosworth, Facebook's VP of virtual and augmented reality, wrote in a blog post.

"The vision for this work is a wristband that lets people control their devices as a natural extension of movement," he said.

As every generation of technology has been subject to a shift in input mechanisms—from the keyboard to the mouse to touchscreen to voice—CTRL-labs hopes it's identified the next major way we'll be interacting with our technology: hands-free gestures.

Typically, BCI systems use either chips implanted in the brain, or electrode-carrying caps worn on the scalp, to collect signals from the brain and translate them into emotional states, communications, or the user's intended movements. CTRL-labs is focusing on the latter, but it's doing it in a different way to many of its competitors. While non-invasive BCIs (those that don't involve a chip directly implanted in the brain) typically use EEG to gather data, CTRL-labs uses EMG. EEG (electroencephalography) measures electrical signals in the brain, while EMG (electromyography) measures those same impulses as they travel down the nerves in the body.

And, rather than use head-worn gear to pick up neural signals, CTRL-labs uses devices worn on the wrist to pick up the neural signals as they arrive at the muscles in the users' hands.

"If you think of your arms and hands as the pipe of information from your brain to the world, the primary way we as humans affect control in the world and make big changes is by moving our muscles, and in particular, our hands. The technology is a way of capturing that information, decoding it, understanding it, and then short-circuiting the path that we currently use to interact with technology," Adam Berenzweig, head of R&D at CTRL-labs, told ZDNet earlier this month.

CTRL-labs' bracelets will gather signals that control hand movements, and pass them onto whichever computer system is connected. "We're cutting out that middleman and decoding neural signals to do whatever you want to do with machines," Berenzweig added.

How might that work in the real world? People using VR could control their systems using their natural movements, rather than carry separate handheld controllers, or people using headsets like Google Glass could navigate with a simple flick of a finger. Gamers and office workers alike could do away with hardware like joypads and mice in favour of making a few gestures—like a touchscreen, but with no need for touch of any kind. In essence, every piece of technology becomes hands-free. For those imagining a Minority Report style future of exaggerated hand-waving, fear not—the system can pick up "tiny wiggles" as much as larger gestures.

"Each of those stages [of technology development] has a new human computer interface paradigm shift… We believe this input technology we have is a perfect fit to be the input for wearable computing, where your hands are the best controllers. You have your hands on all the time, and you don't need another device—you have your own abilities with high precision, high dexterity, expressive hand movements," Berenzweig said.

"The modern VR systems are just great, they're visually beautiful and immersive, you put on a headset and you're feel like you're there and then you still have these sticks where your hands should be. The input side is lagging behind the visual side," Berenzweig added.

While CTRL-labs' likely interest for Facebook is VR—the startup will join Facebook's VR unit—the social network's interest in brain machine interface extends well beyond its latest purchase. In 2017, it was reported the company had a team of 60 people working on brain computer interfaces to allow people to type at 100 words a minute just using brain signals.

In July of this year, the company posted an update on the project, saying it had a functioning system, but one which recorded only a small set of words and phrases. While it's a separate strand of BCI research to CTRL-labs' own, the two are both subject to a common driver: the ability to help those with nerve damage to communicate again. In the case of Facebook's thought-typing program, researchers had previously worked on helping those with locked-in syndrome to communicate and were researching how to help people with neural conditions speak again using BCIs; for CTRL-labs, the device could potentially be used to help those with damage to their nerve pathways overcome paralysis.

"I think this technology is going to have a big impact on people's lives as an assistive device across a pretty wide range of pathologies and ways in which people struggle with using their hands or motor impairment. It's not our focus as a company—we're focused on a mass consumer market, and think about the technology as something that billions of people would be using on a daily basis—but we're aware of all these quite enticing and impactful clinical applications," Berenzweig said.

As long as there are some intact connections from the brain to the muscles of the hands, the CTRL-Labs system should be able to work. "We have partnerships with clinical research labs and we have a board of advisors with a number of research neuroscientists who are beginning to use this in their labs, and this hopefully this will lead into other products and clinical work," he said.

"As far as what kinds of things this could be used to address, [it could include] stuff like muscular dystrophy, MS, ALS, Parkinson's—anything where there's an impairment but the nerves are intact and functioning to some degree," said Berenzweig, adding that the system could also potentially be used in stroke rehabilitation.

MIND-READING SYSTEMS: SEVEN WAYS BRAIN COMPUTER INTERFACES ARE ALREADY CHANGING THE WORLD

From helping people regain their independence to updating Facebook faster, here are some of the ways brain computer interfaces are being trialled and implemented today.

BY: JO BEST

Neuralink may be one of the best-known brain computer interface companies in the world right now, but everyone from big tech to tiny startups and neuroscience researchers are working on projects aimed at linking human minds to computers.

Here are some of the experimental and real-world applications they've come up with so far.


IMAGE: GETTY IMAGES/ISTOCKPHOTO

FIGHTING PARALYSIS

When Ian Burkhart had a diving accident aged 19, he lost the use of his hands and legs. Now, thanks to a BCI, he's able to perform seven different movements with his hand, and even play Guitar Hero.

Burkhart has had an electrode array implanted in his motor cortex—and a separate 'sleeve' that can pass on neural signals to his arms to tell them to move—for over five years, making him one of the longest-standing users of invasive BCIs in the world.

Battelle, the company behind the BCI system, started its work using the technology to overcome spinal injuries several years earlier. There are 5.5 million Americans living with paralysis.

"The aim of the programme was to develop neural-bypass technology that can connect the brain to the hand or the limb that controls, and bypassing the injury to the spinal cord," says Gaurav Sharma, senior research scientist at Battelle.

Now, when Burkhart thinks about moving his hand, the electrical impulses in the motor cortex of his brain—the area that controls conscious muscle movements—are passed directly to the muscles in his hand, leapfrogging the severed nerves in his spine, which are incapable of passing on the messages from the brain themselves due to his injury.

Since using the BCI, Burkhart has moved out from his parents' house, and now lives alone; the amount of time he needs help from a caregiver has also been cut from 12 hours to four hours a day.

Burkhart's motor abilities have also improved even when he's not using the BCI. "Over the last five years he's been using the system, his ability to manipulate objects on his own *without* using the system has improved remarkably... He will tell you he's more coordinated when he's using his own hand to do things—he can open a doorknob, which he wasn't able to do earlier, and he can very easily manipulate his phone," says Sharma.

UPDATING YOUR SOCIALS

Social networks thrive on data, and what better source of fresh, personalised data than the human brain? Facebook has already been working on technology to allow people to type just by thinking. The uses of the technology for the company are obvious: what better way to sidestep the onerous process of, er, picking up your smartphone to post a status update, when you could just think it and have it appear on your feed instead?

There may be an upside for humanity nonetheless: as well as Facebook staffers, the researchers working on the project at the University of California, San Francisco are aiming to use the technology to help people with brain damage recover their ability to speak. The technology underpinning Facebook's effort is high-density electrocorticography (ECoG)—to train the system up, subjects are asked questions with ECoG monitoring, and their neural signals are then matched from the brain to particular speech. The first fruits of Facebook's research have been revealed, demonstrating a working system that is able to recognise a few words and phrases from signals from the brain's speech centre.

CREATING MUSIC THERAPY

A collaboration between researchers—including neuroscientists, biomedical engineers, and musicians—has been looking at the potential for BCIs to be used with music. They are working on a system that could analyse a person's emotional state using their neural signals, and then automatically develop an appropriate piece of music. For example, if you're feeling down, the system's algorithms could write you a piece of music to help lift your mood.

The system has been tested on healthy volunteers, as well as on one individual with the neurodegenerative condition Huntington's disease, which causes depression and low mood.

"Part of the reason someone might have a music therapy session is because they have trouble understanding their own emotions or expressing their own emotions, so the idea is to use music and the skills of the therapist, and potentially this device is better in helping them understand their emotions," says Ian Daly, lecturer at the University of Essex's School of Computer Science and Electronic Engineering.

TELEPATHIC TETRIS

Using BCIs for gaming is one thing, but using them for collaborative gaming? Yep, that's possible too. Arguably more a brain-computer-brain interface than a brain computer one, recent research published by the University of Washington allowed three people to play a Tetris-type game by networking their brains.

The game was the culmination of years of work on machine learning to decode someone's intended movements from an EEG. "There was a question that came up which was, if the signal that you extract is being sent to a robotic device or cursor on a screen, what if you could send that signal directly to a person's brain?" says Rajesh Rao, professor at the University of Washington's Paul G. Allen School of Computer Science & Engineering and a co-director of the university's Center for Neurotechnology.

The game, called BrainNet, requires a collaborative effort between three players to rotate onscreen blocks until they fit into differently shaped gaps below. Two players could see both the gap and block but not rotate the block, while one could rotate the block but not see the gap. To instruct another person to rotate a block, a player would concentrate on the word 'yes' or 'no' on a screen, each linked to an LED flashing at a different rate. EEG caps would read the brain activity corresponding to the particular light, and pass it on to the other player's cap, generating a flash in their field of vision for 'yes' and no flash for 'no', using a technology called transcranial magnetic stimulation. By working together, the teams were able to succeed 80% of the time.

The project was inspired by previous work on brain computer interfaces that aimed to help people with paralysis operate prosthetics, and see if it could be taken to the next level by connecting up the brains of more than one person. "Potentially one could have a proof of concept demonstration of computer-assisted telepathy, or brain-to-brain communication. We asked the question, can we go beyond two people to a network of people, reading from and writing into the brain?" Rao says.

HEALTH AND SAFETY GONE MIND

Neurable's technology is designed to measure emotion, interpret intent and allow people to control their environment using their thoughts. One of Neurable's focuses is virtual reality, for uses including training up staff. By training workers in a simulated environment and measuring their emotional response, employers can gauge their performance and emotional response, and adapt the training as necessary.

"The training space is very interesting. A lot of it's done in virtual reality, a lot of companies are exploring how to make their training more efficient and more successful, and also safer—if you're going to do a dangerous task on an oil rig or a power line, training people in a virtual space is much better to start with, rather than start with the situation and hope they don't get hurt," Jamie Alders, VP of product at Neurable, told ZDNet.

OVERCOMING REPETITIVE STRAIN INJURY

For most office workers, a desk job means using a computer for hours on end every day—and using a computer for hours every day means repetitive strain injury (RSI). Could BCIs offer a more ergonomic way of using technology?

CTRL-labs hopes so: it uses sensing bracelets that detect EMG (electromyography) activity to pick up intended movements in the hands, and relay it to external systems. The bracelet picks up the neural signal sent from the brain and then uses that signal to control a device. One area where this technology could be useful is in VR and AR, where users currently have to make do with controllers with too many buttons that they can't see.

It's a vision that's appealed to one of the biggest names in tech: Facebook acquired the company in September.

Facebook and CTRL-labs' vision for gesture-controlled tech might have a knock on effect on users' health: by using your hands freely in space to control your hardware, rather than another piece of hardware, there should be fewer aches and pains that go alongside using technology.

"Ergonomics is not the most pressing health issue in the world, but millions of people have RSI and that actually affects them on a daily basis and they have to stop working and typing… I think this technology will go the other way; we will adapt to what the person wants to do and it has the possibility to be a much more comfortable and natural way to interact with technology," says Adam Berenzweig, head of R&D at CTRL-labs

HELPING PEOPLE WITH LOCKED-IN SYNDROME COMMUNICATE

People with locked-in syndrome are entirely mentally aware, but can move none, or almost none, of their muscles. They can't speak or write; their ability to communicate with the outside world is limited to perhaps moving an eyelid or a single finger when asked a question.

BCIs are opening up new options for those with locked-in syndrome to communicate more fully, being able to use their brain signals to choose letters in order to write messages, send emails and respond to questions.

A variety of methods have been used to pick up the brain signals of people with locked-in syndrome, including NIRS optodes, which pick up metabolic activity in the brain, and intracortical local field potentials, which read electrical activity.

MIND-READING TECHNOLOGY IS EVERYONE'S NEXT BIG SECURITY NIGHTMARE

While the hardware can be made as secure as possible, turning our thoughts into a digital form will put them at risk just like any other data.

BY: JO BEST

Technology allowing our thoughts and feelings to be translated into a digital form—and shared—is already a reality. Brain computer interfaces (BCI) allow us to connect our minds to computers for some limited purposes, and big tech companies including Facebook and many startups want to make this technology commonplace.


IMAGE: GETTY IMAGES/ISTOCKPHOTO

For those of you terrified by the prospect of technology recording—and broadcasting—your opinions of the boss, your secret fears, or anything else—relax.

At least, for now.

BCIs are currently not sophisticated enough to collect such granular information. The data they can gather is more based around measuring the physical movements people want to make or their emotional state. But, as machine-learning algorithms become more sophisticated and BCI hardware becomes more capable, it may be possible to read thoughts with greater precision.

There are currently two approaches to connecting up the human brain to external computing systems, invasive and non-invasive.

Non-invasive systems read neural signals through the scalp, typically using EEG, the same technologies used by neurologists to interpret the brain's electrical impulses in order to diagnose epilepsy. Non-invasive systems can also transmit information back into the brain with techniques like transcranial magnetic stimulation, again already in use by medics.

Invasive systems, meanwhile, involve direct contact between the brain and electrodes, and are being used experimentally to help people that have experienced paralysis to operate prostheses, like robotic limbs, or to aid people with hearing or sight problems to recover some element of the sense they've lost.

Clearly, there are more immediate hazards to invasive systems: surgery always brings risks, particularly where the delicate tissue of the brain is concerned. So given the risks involved, why choose an invasive system over a non-invasive system—why put electronics into your grey matter itself? As ever, there's a trade-off to be had. Invasive systems cut out the clutter and make it easier to decode what's going on in the brain.

Non-invasive systems use the likes of EEG to read brain activity, which need millions of neurones acting in sync with each other to give a usable idea of what's going on in the brain by creating a large enough electrical field that can be detected outside the surface of the scalp. But it's a very crude measure.

"It's the equivalent of standing outside a football stadium and trying to work out what's going on in the game just by listening to the cheers. You can get a picture of some of the big events, but it's difficult to get fine-grained information," says Ian Daly, lecturer at the University of Essex's School of Computer Science and Electronic Engineering.

Invasive systems, however, are in direct contact with the neurones—so even though they may only gather a signal from a hundred neurones, that signal is clear enough to give an insight into the thought process travelling through it.

Take Ian Burkhart, a man with paraplegia who regained some function of arms using a neurosleeve and software by US-based BCI company Battelle, as well as a Utah Array implanted into his brain. Typically, the thought required to move an arm is the job of thousands of neurones; Burkhart can move the Battelle system with just a few tens of neurones after training himself to use the system. "Our brain has 98 billion neurones, the motor cortex has 1.2 billion responsible for hand or limb movements. We are recording from less than 100," says Gaurav Sharma, senior research scientist at Battelle.

To date, most uses of invasive systems have been aimed at helping people with paralysis to move their limbs once again; the greater risks of invasive systems can be worth the payoff for them.

As such, for consumer-tech applications, the short to medium term future of BCIs is likely to be non-invasive.

While non-invasive systems may not match the accuracy of their invasive counterparts, there are new technological avenues opening up that could help researchers level-up non-invasive systems. For example, progress in machine learning is helping scientists better separate the signals from the noise, meaning the accuracy of non-invasive systems will only increase in future.

As well as software improvements, additional scanning types are beginning to be used by BCI systems: focused ultrasound and transcranial direct-current stimulation, for example, might offer a new way to read brain signals.

Others believe that existing non-invasive technologies can deliver the same brain-reading capabilities as invasive systems—at least when it comes to motor control.

New York-based CTRL Labs for example uses EMG (electromyography), which reads the electrical activity in skeletal muscle and is used by neurologists to detect nerve performance in the limbs and elsewhere. CTRL Labs makes wrist bands that measure electrical impulses, known as action potentials, in neurones within muscles, and models them in software. When you move your hand, the CTRL Labs system translates that as a hand movement, including its direction, strength and type. It was acquired by Facebook earlier this month.

"We believe that if what you're interested in doing is control you can get all the signal you want and get it more easily through non-invasive means", Adam Berenzweig, head of R&D at CTRL Labs, told ZDNet earlier this month.

"The signal you want is available on surface EMG if you do it well enough, and more than that, the signal is easier to get because in the cortex, all the billions of neurones in the brain are interfering and are noise," says Berenzweig. So if all you're interested in is picking up movement signals from the brain, in most people, non-invasive systems might still do the trick.

While invasive systems will continue to be used by those with the greatest amount to gain from BCIs, such as people with spinal injuries or neurological conditions like Parkinson's disease, broader uptake among consumers is likely to be concentrated on non-invasive systems.

Because reading signals from the brain through the scalp requires direct contact between the skin and the electrodes, it makes unwanted reading of anyone's thoughts at source unlikely and highly noticeable—you'd expect most people would be aware of a stranger unexpectedly touching their head, especially with a set of electrodes. Mind reading at source would be too easy to detect.

That said, once the data is collected by BCI and passed on to other software, it's just as secure as any other set of information. In the wake of many, many data breaches it's clear there are no guarantees that sensitive information is better protected than other kinds of data.

Finding out that your information has been accessed by a data breach is never pleasant, but that someone could have been browsing your thoughts patterns or emotional states? It doesn't bear thinking about.

MIND-READING TECHNOLOGY: THE SECURITY AND PRIVACY THREATS AHEAD

Brain computer interface technology is developing fast. But just because we can read data from others' minds, should we?

BY: JO BEST

IMAGE: GETTY IMAGES/ISTOCKPHOTO

Since the dawn of humanity, the only way for us to share our thoughts has been to take some kind of physical action: to speak, to move, to type out an ill-considered tweet.

Brain computer interfaces (BCIs), while still in their infancy, could offer a new way to share our thoughts and feelings directly from our minds through (and maybe with) computers. But before we go any further with this new generation of mind-reading technology, do we understand the impact it will have? And should we be worried?

Depending on who you listen to, the ethical challenges of BCIs are unprecedented, or they're just a repeat of the risks brought about by each previous generation of technology. Due to the so-far limited use of BCIs in the real world, there's little practical experience to show which attitude is more likely to be the right one.

THE FUTURE OF PRIVACY

It's clear that some ethical challenges that affect earlier technologies will carry across to BCIs, with privacy being the most obvious.

We already know it's annoying to have a user name and password hacked, and worrying when it's your bank account details that are stolen. But BCIs could mean that eventually it's your emotional responses that would be stolen and shared by hackers, with all the embarrassments and horrors that go with that.

BCIs offer access to the most personal of personal data: inevitably they'll be targeted by hackers and would-be blackmailers; equally clearly, security systems will attempt to keep data from BCIs as locked down as possible. And we already know the defenders never win every time.

By the time BCIs reach the consumer world, something like privacy settings—like when browser or app users turn services on or off, according to whether the services cross their own personal privacy threshold—might also be deployed around BCIs.

One reason for some optimism: there will also be our own internal privacy processes to supplement security, says Rajesh Rao, professor at the University of Washington's Paul G. Allen School of Computer Science & Engineering.

"There's going to be multiple protective layers of security, as well as your brain's own mechanisms for security—we have mechanisms for not revealing everything we're feeling through language right now. Once you have these types of technologies, the brain would have its own defensive mechanisms which could come into play," he told ZDNet.

THE MILITARY MIND

Another big issue; like generations of new technology from the internet to GPS, some of the funding behind BCI projects has come from the military.

As well as helping soldiers paralysed by injuries in battle regain the abilities they've lost, it seems likely that military's interest in BCIs will lead to the development of systems designed to augment humans' capabilities. For a soldier, that might mean the chance to damp down fear in the face of an enemy, or patch-in a remote team to help out in the field—even connect to an AI to advise on battle tactics. In battle, having better tech than the enemy is seen as an advantage and a military priority.

There are also concerns that military involvement in BCIs could lead to brain computer interfaces being used as interrogation devices, potentially being used to intrude on the thoughts of enemy combatants captured in battle.

THE ONE PERCENT GET SMARTER

If the use of BCIs in the military is controversial, the use of the technology in the civilian world is similarly problematic.

Is it fair for a BCI-equipped person with access to external computing power and memory to compete for a new job against a standard-issue person? And given the steep cost of BCIs, will they just create a new way for the privileged few to beat down the 99 percent?

These technologies are likely to throw up a whole new set of social justice issues around who gets access to devices that can allow them to learn faster or have better memories.

"You have a new set of problems in terms of haves and have nots," says Rao.

This is far from the only issue this technology could create. While most current-generation BCIs can read thoughts but not send information back into the brain—future generation BCIs may well be able to both send and receive data.

The effect of having computer systems wirelessly or directly transmit data to the brain isn't known, but related technologies such as deep brain stimulation—where electrical impulses are sent into brain tissue to regulate unwanted movement in medical conditions such as dystonias and Parkinson's disease—may cause personality changes in users (though the strength of the link is still a matter of debate).

And even if BCIs did cause personality changes, would that really be a good enough reason to withhold them from someone who needs one—a person with paraplegia who requires an assistive device, for example?

As one research paper in the journal BMC Medical Ethics puts it: "the debate is not so much over whether BCI will cause identity changes, but over whether those changes in personal identity are a problem that should impact technological development or access to BCI".

Whether regular long-term use of BCIs will ultimately effect users' moods or personalities isn't known, but it's hard not to imagine that technology that plugs the brain into an AI or internet-level repository of data won't ultimately have an effect on personhood.

Historically, the bounds of a person were marked by their skin; where does 'me' start with a brain that's linked up to an artificial intelligence programme, where do 'I' end when my thoughts are linked to vast swathes of processing power?

It's not just a philosophical question, it's a legal one too. In a world where our brains may be directly connected to an AI, what happens if I break the law, or just make a bad decision that leaves me in hospital or in debt?

THE CORPORATE BRAIN DRAIN

And another legal front that will open up around BCI tech could pit employees against employer.

There are already legal protections built up around how physical and intellectual property are handled when an employee works for and leaves a company. But what about if a company doesn't want the skills and knowledge a worker built up during their employment to leave in their head when they leave the building?

Dr S Matthew Liao, professor of bioethics at New York University, points out that it's common for a company to ask for a laptop of phone back when you leave a job. But what if you had an implant in your brain that recorded data?

"The question is now, do they own that data, and can they ask for it back? Can they ask for it back—every time you leave work, can they erase it and put it back in the next morning?"

Bosses and workers may also find themselves at odds in other ways with BCIs. In a world where companies can monitor what staff do on their work computers or put cameras across the office in the name of maximum efficiency, what might future employers do with the contents of their BCIs? Would they be tempted to tap into the readings from a BCI to see just how much time a worker really spends working? Or just to work out who keeps stealing all the pens out of the stationery cupboard?

"As these technologies get more and more pervasive and invasive, we might need to read to rethink our rights in the workplace," says Liao. "Do we have a right to mental privacy?"

Privacy may be the most obvious ethical concern around BCIs, but it's for good reason: we want our thoughts to remain private, not just for our own benefit, but for others' as well.

Who hasn't told a lie to spare someone's feelings, or thought cheerfully about doing someone harm, safe in the knowledge they have no intention of ever doing so? Who wouldn't be horrified if they knew every single thought that their partner, child, parent, teacher, boss, or friend thought?

"If we were all able to see each other's thoughts, it would be really bad - there wouldn't be any society left," said Liao.

If BCIs are to spread, perhaps the most important part of using 'mind-reading' systems is to know when to leave others' thoughts well alone.

NEURAL IMPLANTS: WHY CONNECTING YOUR BRAIN TO A COMPUTER WILL CREATE A HUGE HEADACHE FOR EVERYONE

Brain-machine interfaces could bring major benefits—and major risks, which could increase if big tech is allowed to dominate another new technology.

BY: STEVE RANGER

Technology that allows us to connect our minds to computers will have such huge implications that the government needs to look at the ethical risks involved, and ensure that developments are not dominated by big tech companies.


IMAGE: GETTY IMAGES/ISTOCKPHOTO

A report from the Royal Society—the UK's national science academy—said the government should launch an investigation into neural interface technologies, including looking at regulations around their development and the ethics of using them.

Neural interfaces are devices implanted in the body, or worn externally, which are capable of recording or stimulating activity in the brain. The idea of such technology, also known as brain computer interfaces (BCI), isn't all that new: many people worldwide already benefit from medical neural interface technologies like the cochlear implants that provide hearing for around 400,000 people, while people otherwise unable to communicate have been able to spell out words using brain signals alone.

But BCI could be on the verge of explosive growth: the Royal Society report suggests the technology is at the same stage as computing was in the 1970s. The report predicts than within a couple of decades neural interfaces could be used to help people to walk after paralysis, tackle depression, or even help to treat diseases like Alzheimer's.

The Royal Society experts predict that, in future, "people could become telepathic to some degree" as more sophisticated neural interfaces emerge and allow us to connect to computers—or to each other.

"Linking human brains to computers using the power of artificial intelligence could enable people to merge the decision-making capacity and emotional intelligence of humans with the big data processing power of computers, creating a new and collaborative form of intelligence. People could become telepathic to some degree, able to converse not only without speaking but without words—through access to each other's thoughts at a conceptual level," the report said.

Big tech companies are eyeing neural interfaces as a potentially rich area of development. Facebook has previously said that it is working on mind-reading technology that would allow users to think messages onto a screen rather than type them, or even to share thoughts independent of language.

But it's Elon Musk's Neuralink project that seems to be making the most impact at the moment, working to create ultra-high-bandwidth brain computer interfaces to connect humans and machines. Musk has warned that the rise of artificial intelligence is one of the greatest threats to humanity, and neural interfaces could be one way to reduce the risk by giving us a chance to keep up with the machines.

The Royal Society warned that if developments are dictated by a handful of companies then less commercial applications could be sidelined. It said regulation should not be so onerous, complicated and expensive that it allows 'big tech' to dominate the emerging field.

The benefits could include not just better health, but sharper memories, and better concentration and more intimate connections with those around us. The downsides include the potential for our most intimate or fleeting thoughts or moods being accessed by companies or governments. Hacking into these implants could have serious consequences, and it's hard to think of a richer target for hackers. More broadly, if only the rich can afford augmentation, that could have implications for social inequality.

The Royal Society said that the government needs to investigate the ethical issues presented by neural interfaces, to address questions of what data should be collected, how it is kept safe, and the acceptability of enhancements. It said that authorities should also look at how innovation can be encouraged to prevent a monopoly by 'big tech' firms.

"While advances like seamless brain-to-computer communication seem a much more distant possibility, we should act now to ensure our ethical and regulatory safeguards are flexible enough for any future development," said Dr Tim Constandinou, director of the Next Generation Neural Interfaces (NGNI) Lab at Imperial College London. "In this way we can guarantee these emerging technologies are implemented safely and for the benefit of humanity."

10 YEARS FROM NOW YOUR BRAIN WILL BE CONNECTED TO YOUR COMPUTER

Brain-machine interfaces will be increasingly common, with consumer and business applications as well as medical.

BY: STEVE RANGER

Connecting your brain to a computer and communicating will be a reasonably common activity within a decade or so, with tens of millions of brain-machine interface (BMI) devices sold every year.


IMAGE: GETTY IMAGES/ISTOCKPHOTO

BMIs (Brain Machine Interfaces) are an intriguing area of research with huge potential, offering the ability to directly connect the human brain to computers to share data or control devices.

Some of the work on BMI is one step away from science fiction. Probably the best-known company working on this technology today is Neuralink, the Elon Musk-backed firm that aims to develop ultra-high bandwidth 'neural lace' devices to connect humans and computers.

At least part of the reason for Musk's interest in the idea of mind brain-computer connections is that such technology could stop humans getting left behind by a (still to emerge) super-intelligent artificial intelligence. The idea is that connecting our minds directly to the AI with high bandwidth links would at least give us a chance to keep up with the conversation.

However, more basic forms of BMI technology have been used in medicine for years, like cochlear implants which provide a sense of sound to a person who is profoundly deaf or severely hard of hearing. Another emerging medical use case is visual prosthetics—using an artificial device to restore a form of sight.

But more ambitious forms of BMI—like controlling or communicating with computers or digital avatars—are still at a very early stage.

Even so, tech analyst Juniper Research predicts that shipments of BMI devices will reach 25.6 million by 2030, up from roughly 350,000 in 2019. It forecasts that over that timeframe BMIs will expand beyond pure experimental medical use cases, with consumer uses developing. It's a small number—more niche than smartwatches are today—but more common than many would expect if the analysts are right.

Such devices will offer the ability to control virtual reality scenarios; enhancing the user experience and immersion level, as well as potentially offering wellness functions, such as supporting guided meditation and enhancing sleep quality, according to the analysts.

Beyond this, Juniper said there is significant scope for BMI devices in areas like gaming and smart home control although high prices, the need for calibration and the early stage of development will mean that it will remain a niche prospect. There are also other uses: for example, monitoring when fatigue or a loss of concentration can be a big risk.

"On a production line, a lapse in concentration could result in hundreds of incorrect products, or an accident. In the military, a lapse in concentration could result in the injury or death of service personnel. Strategies leveraging BMI technology to improve concentration are important and a potentially vast source of revenue," the analysts said.

Juniper said that medical devices will drive revenues throughout the period; accounting for 78% of total revenues in 2030. "Medical devices, such as experimental visual and limb prosthetics, will be highly expensive, with extensive research and clinical trials required in order to reach their full potential," it said. The analysts said that of all the potential interface technologies, electroencephalography (EEG) will remain the most dominant.

While Juniper said EEG is "highly susceptible" to interference, it is affordable given its existing prevalence in medical fields, as well as non-invasive (unlike, for example, direct implantation of devices), which is crucial for consumer adoption; few will be willing to have their brains exposed to surgery just to make VR games a bit more fun.

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